The Washington Water

RESOURCE

The quarterly report of the Center for Urban Water Resources Management

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Message from the Director

For the second year running the Center has joined forces with our sister center in Forestry and Fisheries, the Center for Streamside Studies, and will co-host the next presentation of research results from the two centers on **Wednesday, February 6, 2002** in the HUB West Ballroom on the University of Washington campus. This is a full-day affair that hosted more than 300 people last year and is still provided at no cost to the public and professional community. The preliminary schedule of the day is given below; additional information will be posted on the CSS web site, http://depts.washington.edu/cssuw/, as the date gets closer.

Our two centers continue to move closer to joint operation in many other capacities. The Annual Review is one of the most visible expressions of that trend, but we are also working to integrate research and educational efforts in order to dissolve the arbitrary (and generally unproductive) divisions that can be perceived between "urban" and "forestry" approaches to water-resource issues.

In addition to planning for the Annual Review, the end-of-year season also brings us to the time that Center subscription renewals for 2002 will be sent out, planned for mid-January. Subscriptions cover the cost of the newsletter and help support many of the ongoing, cooperative functions of the Center as well. A final upcoming year of support from the College of Forest Resources continues to allow us to maintain the same subscription rates that have been in effect since the Center began in 1990. I also remind you that all are welcome to add additional recipients of the newsletter to your subscription without charge, because our interests are all best served through the broadest distribution of information.

After a flurry of activity up until the end of the summer, the 2001 Stream Temperature Survey has reached an impasse in data analysis, only a few short days shy of completion. We have 485 new temperature measurements on nearly 100 individual streams, ranging from 9 to 24 °C, with over 50 replicate measurements (same site, different times and/or different people) to evaluate the overall quality of the data set. The data should be posted on the Center's web site by early 2002, but if you have need or interest in it earlier, feel free to email us for an advance copy. Many thanks, as always, for the nearly 100 volunteers this year that made the work possible.

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MESSAGE FROM THE DIRECTOR
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Preliminary Schedule, Annual Review of Research for the Center for Urban Water Resources Management and the Center for Streamside Studies

Wednesday, February 6, 2000, 8:30-4:15, HUB West Ballroom, University of Washington Campus, Seattle.

8:30 **Opening remarks**

8:45 *Why do they care? Landscape management for nonpoint source pollution by small parcel owners*
Kathleen L. Wolf

9:00 *A study of periphyton induced pH spikes on the White River, Washington*
Derek Stuart

9:15 *Regional stream temperature estimation using thermal infrared remote sensing and ground measurements*
Keith Cherkauer

9:30 *Heavy metal contamination from abandoned mines and its effect on organisms in the Methow River in Okanogan County, Washington*
Dan Peplow

9:45 *Land management for nonpoint source pollution: Methods and motivations*
Clare M. Ryan

10:00 **Break and Poster Session**

10:15 *A daily time series analysis of urbanization effects on stream phosphorus concentrations and transport in the greater Seattle region*
Sara Stanley

10:30 *Urbanization impacts on stream nutrient concentrations*
Mike Brett

10:45 *Opportunities for benign hydrologic design in urban areas*
Rich Horner

11:00 *Assessing the availability of spawning gravel in an urban creek system*
Chase Barton

11:15 *Variability of hyporheic flows in Puget Sound lowland streams*
Cathy Reidy

11:30 *Protecting physical stream channels with classic stormwater mitigation: Fact or fantasy*
Karen Comings

11:45 **Lunch Break and Poster Session—dessert provided**

1:15 *The development and organization of old growth river valley forests*
Kevin Fetherston

1:30 *Spawning salmon as forest fertilizer: effects on riparian structure and composition*
Krista Bartz

1:45 *When is hydrologic maturity: Inferring temporal change in hydrologic response from paired streamflow data*
Finn Krogstad

2:00 *Short-term suspended-solid concentrations from stream crossing restoration work in the Clearwater NF, Idaho*
Tim Brown

2:15 *Ten years after: Evaluation of restoration efforts*
Mark Muir

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2:30 **Break and Poster Session**

2:45 *Flow regimes of charr spawning streams: Implications for bedload scour during the incubation period*
Jeff Shellberg

3:00 *Multi-scale prioritization of riparian habitat restoration and preservation*
Raymond Timm

3:15 *Nonmigratory coastal cutthroat trout: Evidence for restricted gene flow among neighboring creeks*
Josh Latterell

3:30 *The phylogeny of behaviour: Salmoninae spawning patterns*
Manu Estevé

3:45 *Changing temperature regimes and the spawning timing of coho and chinook salmon*
Tom Quinn

4:00 **Closing Remarks**

Posters:

- Riparian canopy cover and its effects on stream temperature in eastern Washington (Ashley Adams)
- Microbial production in the hyporheic zone of a coastal floodplain river (Sandra Clinton)
- The effect of marine-derived nutrients on secondary production of macroinvertebrates in a salmon spawning stream (Jon Honea)
- Short-term tree fall patterns from riparian buffers (Mike Liquori)
- Impacts of riparian vegetation on in-stream ecosystems and nutrient dynamics (Carol Volk)
- Ecological role of estuarine large woody debris supporting juvenile Pacific salmon (Ali Wick)
- Evaluation of North Creek channel conditions. ❖

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Hydrologic Trends and Hydrologic Monitoring in Urbanizing Streams of Western Washington

Christopher P. Konrad, U. S. Geological Survey, Water Resources Division, and Derek B. Booth, University of Washington, Center for Urban Water Resources Management

1. INTRODUCTION

This study was initiated to explore the use of specifically *hydrologic* monitoring elements to evaluate the condition of lowland watersheds and the effectiveness of hydrologic mitigation (typically, detention ponds). Its specific purpose is to develop and make recommendations for a method to measure changes to the hydrologic regime of streams in urbanizing watersheds that are relevant to the ecological health of those streams, and to assess the practicalities, including the sensitivity and the minimum duration of monitoring, of implementing such a method. This work was based on hydrologic analyses first published in the Fall 2000 issue of the Newsletter, now focused to help answer the question, "Is the hydrologic regime of this stream improving or declining over time?"

1.1. Overview of the Effects of Urban Development

When vegetation is cleared from hillslopes in a stream basin, the land surface is graded, and building and roads are constructed, the resulting urban landscape causes a variety of changes in the downstream channels. These development activities generally reduce the storage of stormwater on hillslopes, and they shorten the time required for stormwater to travel over and through a hillslope to a stream. As a result, some of the most significant characteristics unique to urban, or urbanizing, streams are their increased peak discharge rates and their rapid rise and recession of storm flows. These hydrologic consequences of urban development can cause both social and ecological damage, including increased flooding and bank erosion, increased contaminant transport, and changes to instream habitat. Yet the "classic" metrics of urban-induced hydrologic change, such as the fractional increase in the 2-year discharge, are poorly suited to characterize the magnitude of such changes, because they do not facilitate comparisons between basins and they do not have any demonstrable (or even plausible) linkage with other important instream conditions, particularly biological health.

1.2. Stream Flow Variability

The hydrologic effects of urban development, and the stormwater management activities intended to mitigate those effects, are not easily evaluated because streamflow varies over time. Although this short-term variability confounds monitoring it may be of little direct ecological significance, because biological conditions in streams re-establish quickly, often within months, after hydrologic disturbances such as floods and droughts (Boulton et al., 1992; Bayley and Osborne, 1993; Jones et al., 1995). In contrast, changes in stream flow patterns over annual or multiple-year time scales are likely to have a persistent influence on the biological conditions of urban streams (Poff et al., 1997).

Thus the temporal variability of streamflow at the scale of both storms and seasons, and the resilience of biological systems to these short-term changes, precludes the use of short-term streamflow patterns for monitoring anthropogenic effects. Even annual streamflow statistics, such as maximum annual peak flow or summer low flow, may vary by as much as an order of magnitude from year-to-year even without changes in land use, because of broad multi-year weather patterns such as El Nino-Southern Oscillation and the Pacific Decadal Oscillation. In consequence, anthropogenic changes in streamflow patterns are only likely to be detected where the change is large relative to the variation caused by climatic conditions. The hydrologic effects of urban development may be evident only for streams with extensive urban development and hydrologic data that span a relatively long period of time.

2. METHODS

2.1. Streamflow Metrics

Existing stream-gage records can be used to determine exactly what streamflow patterns are most expressive of anthropogenic change, to evaluate the improvement in statistical confidence of using records of progressively longer duration, and to determine the minimum length of record that is likely to yield any useful conclusions whatever. Beginning with the general, long-understood effects of urbanization on watershed hydrology (Hollis, 1975; Leopold, 1968; Booth 1991) and our expectation of the hydrologic determinants of ecological health, we investigated four metrics from existing gage records that characterize a range of streamflow patterns: the mean discharge rate, the fraction of the year that the mean discharge rate is exceeded, the minimum 7-day mean discharge rate, and the maximum (instantaneous) discharge rate. They are each described below:

1. ***The mean discharge rate (Q_{mean})*** provides a broad measure of flow in a stream. The magnitude of Q_{mean} in western Washington streams is typical of periods of winter baseflow and stormflow recession. Urban development is not

	1995 Land use	Drainage area (km²)	Period of record	
			Daily values	*Max values*
Leach	Urban	12	1958-1985 1989-1998	1958-1998
Juanita	Urban	17	1964-1990	1964-1991
Huge	Rural	17	1947-1969 1978-1998	1948-1998
Swamp	Suburban	25	1964-1990	1964-1990
Mercer	Urban	31	1956-1998	1956-1998
			1965-1971 1989-1990 1993-1998	
Big Beef	Rural	35	1970-1981 1996-1999	1970-1981 1996-2000
Newaukum	Rural	70	1945-1950 1953-1998	1945-1998
Issaquah	Rural	145	1964-1998	1964-1998
Soos	Suburban	171	1961-1999	1961-1999

Table 1.
Western Washington Streams Used in this Analysis

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anticipated to have a systematic effect on Q_{mean}, unless there is extensive irrigation with water imported from other basins or pumped from aquifers.

2. ***The fraction of the year that Q_{mean} is exceeded (T_{Qmean})*** is measured by counting the number of days in a given water year (October 1-September 30) that the daily mean discharge rate exceeds that year's overall Q_{mean}. T_{Qmean} provides a measure of the relative distribution of stormflow to baseflow in a stream—where peak discharges are large and inter-storm baseflow is low, the classic picture of a "flashy" hydrograph, the large peaks will maintain a relatively high value of Q_{mean} but the hydrograph will spend relatively little time above that value. Thus T_{Qmean} will show high values for streams where baseflow is high and stormflow is subdued, and it is anticipated to decline in streams during periods of urban development as runoff is re-distributed from stormflow recession and baseflow to stormflow peaks. T_{Qmean} can also be calculated from shorter unit values (*e.g.*, 15-minute mean discharge), although these results are not likely to differ by more than 0.05 (*i.e.* 5 percent of the year) from the value calculated from mean daily discharges (Konrad, 2000).

3. ***The minimum 7-day mean discharge rate (Q_{min})*** provides a measure of magnitude of streamflow during summer baseflow conditions. Although a reduction in this metric is an oft-anticipated consequence of urban development, reported data simply do *not* support such a universal assertion. Klein (1979) studied 27 small Maryland watersheds and concluded that baseflow dropped by as much as 90 percent with predominantly impervious land cover. Simmonds and Reynolds (1982) estimated the volume of baseflow as a fraction of total stream flow on a part of Long Island, New York, and found an inverse correlation with the amount of urban development. The greatest change occurred with the construction of both sanitary sewers and storm sewers, which reduced the baseflow proportion from 95 percent to only 20 percent. When septic systems remained in urbanized (storm-sewered) areas, the baseflow proportion dropped but only to 84 percent. Yet in those parts of Long Island where recharge (infiltration) basins are the primary means of stormwater disposal, annual streamflow has actually *increased* by 12 percent (Ku and others, 1992). Similarly, data on the distribution of seasonally dry streams in the Puget Lowland (Booth and Wall, 1998) show no systematic differences in the minimum watershed size of perennial (*i.e.* baseflow-supported) streams draining urban or non-urban landscapes (Konrad, 2000).

4. ***The maximum (instantaneous) discharge rate (Q_{max})*** in any given year provides a measure of the magnitude of streamflow during large storms. Q_{max} increases in response to urban development in a stream basin, particularly for smaller magnitude events where the increases can be as much as an order of magnitude (Hollis, 1975). More typical increases for less frequent (but more potentially damaging) storms, evaluated most rigorously through the use of continuous hydrologic models (*e.g.*, King County, 1991), show typical two- to three-fold increases following urban development. This is approximately the same range of variability imposed by fluctuation in year-to-year weather conditions, even in the absence of any watershed changes.

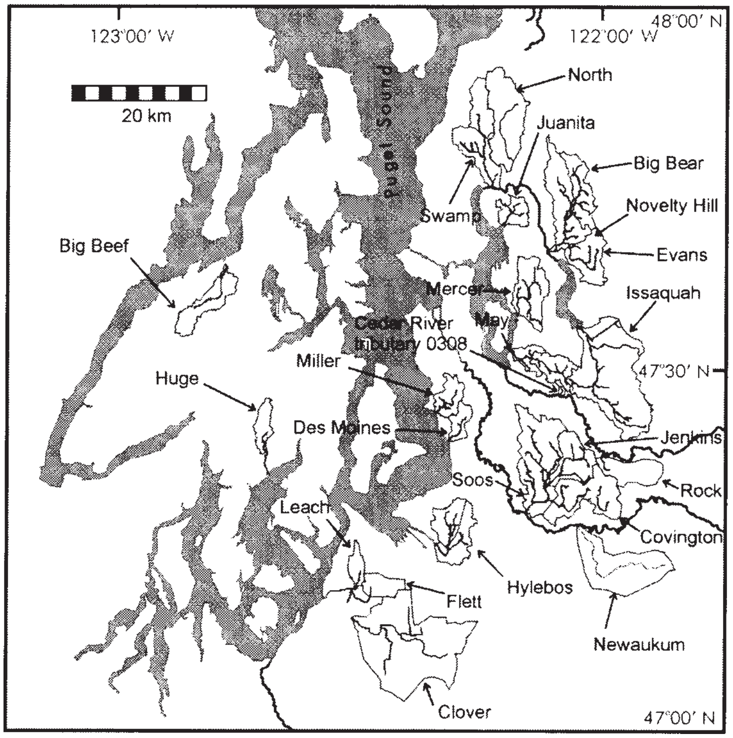

Figure 1.
Location of watersheds discussed in text.

2.2. Streamflow Records

To evaluate the utility of these four metrics to characterize hydrologic change as a result of urban development, we sought long-term gage records from those watersheds having some level of ongoing urban development. Because the era of active stormwater management in western Washington is less than two decades old, such extensive records are generally limited to those of the U. S. Geological Survey, whose gaging program has generally emphasized large rivers on the nation's waterways.

Despite such limitations, we identified 10 potentially suitable streams in western Washington with gage records spanning at least 20 years (Table 1). We focused on streams with drainage areas less than 200 km^2 (about 80 mi^2) in the Puget Lowland, where most of the urban development in the region has occurred. We excluded larger rivers and mountain streams because none have extensive urban development relative to other land use in their basins. Furthermore, their physiographic differences (*e.g.*, mountain headwaters) and hydrologic differences (because runoff there is generated by snowmelt, and channel routing can be very significant) could influence the annual variation in streamflow statistics such that they would not be comparable to smaller, lowland streams. Land use (*ca.* 1995) in the streams' basins were discriminated as "urban," "suburban," or "rural" based on road density (Konrad, 2000).

2.3. Trend Analysis

Trends in the streamflow statistic were evaluated with a two-sided test for correlation between each statistic and time using Kendall's t correlation coefficient (Helsel and Hersh, 1993, p. 212):

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$$\tau = \frac{2(I-D)}{n(n-1)}$$

where: *I* is the number of pairs of annual values of a statistic that have an increasing value over time, *D* is the number of pairs of annual values that have a decreasing value over time, and *n* is the total number of annual values of the statistic.

The probability of observing the statistic, S = P-M, is used to test the statistical significance of a trend. S-PLUS 2000 (MathSoft, 2000) was used to perform the tests. The statistics were tested for trends over the period of record for each stream.

2.4. Error Analysis

Tests for anthropogenic trends in streamflow patterns are likely to produce a relatively high error rate because of the high annual variability in streamflow. Hydrologic trends can emerge over a shorter periods of record that are *not* significant over the total period of record, and thus these are unlikely to be a consequence of urban development (which tends to be monotonic, and permanent, in its effects). These short-term trends are instead a result of climatic conditions that persist for a few years to a decade; if mistakenly identified as a "consequence of urbanization" they would represent Type I statistical errors (false positives). Alternatively, measured hydrologic change over a relatively short period may not be statistically significant, even though a significant trend did exist over the entire period of record. In such cases, a statistical test would not recognize the importance of the short-term change and so produce a Type II error (false negative).

The error rates of trend tests for each individual stream were analyzed by comparing the results of trend tests for selected intervals to the results of the test over the whole period of record. A sensitivity analysis was also performed to assess the influence of the streamflow record length on error rates. To accomplish this, Kendall's t test was applied to 5-, 10-, and 20-year periods of record. Five-year trends were analyzed for the periods beginning in 1960, 1965, 1970, 1975, 1980, 1985, and 1994. Ten-year trends were analyzed for periods beginning in 1960, 1965, 1970, 1975, 1980, and 1985. Twenty-year trends were analyzed for the periods beginning in 1960, 1965, and 1970 (although data were not available for all periods in all streams). Type I errors (false positives) were identified for any stream that had a statistically significant trend over the 5-, 10-, and 20-year period but did not have a trend, or had a trend of the opposite direction, over the whole period of record. Type II errors (false negatives) were identified for any stream that showed no statistically significant trends during any of the 5-, 10-, and 20-year periods but did have a trend over the whole period of record.

Step-trends, or differences in the value of a statistic between two multiple-year periods, were analyzed with Student's t-test (Helsel and Hirsh, 1993, p. 124). Student's t-test can only be applied to groups of normally distributed variables. By inspection we judged that annual values of Q_{mean}, T_{Qmean}, and Q_{min} are normally distributed and performed a logarithmic transformation of Q_{max} before applying the test.

One-sided t-tests were employed to evaluate the likelihood of Type I errors (test shows a significant difference in the value of the statistic between two time periods in a stream where there was no trend) and Type II errors (test shows no significant difference between values of a statistic between two time periods in a stream where there was a trend). Five-year and ten-year mean values of the statistics were calculated for consecutive periods and for periods separated by 5 years.

3. RESULTS

3.1. Trends Over the Period of Record

The results of the tests for trends over the periods of record for all streams using Kendall's t test are provided in Table A1 and graphed in Figures A1 and A2 (included at the end of this report). Although all statistics exhibited trends, only T_{Qmean} and Q_{max} consistently exhibited trends in the three streams with high levels of urban development: Mercer, Juanita, and Leach creeks. Q_{max} increased significantly in all three "urban" streams. T_{Qmean} decreased significantly over time ($p < 0.05$ of no trend) in Mercer and Juanita creeks; Leach Creek (and also Huge Creek, one of the "rural" streams) also had a decreasing trend in T_{Qmean} but it was not statistically significant ($0.05 < p < 0.06$ of no trend). None of the "suburban" or other rural streams had significant trends in either Q_{max} or T_{Qmean}.

Trends in Q_{mean} and Q_{min} were not consistently observed for either individual streams or the overall groupings of urban, suburban, or rural streams. A significant increase in Q_{mean} was detected in Leach Creek but not in Mercer or Juanita creeks (urban), and significant decreases were detected in Newaukum and Issaquah creeks. Significant increases in Q_{min} were detected in Mercer, Swamp, and Big Beef creeks. Only Issaquah Creek showed a significant decrease in Q_{min}, accompanying its unique (at least among this population of streams) decrease in Q_{mean}.

3.2. Trends Over Shorter Periods

Trends in streamflow statistics over more limited periods (5, 10, and 20 years) were analyzed in Juanita, Mercer, Leach, and Soos creeks using Kendall's t test. Error rates were generally high for all statistics (Table A2). Type I error rates (false positives) were below 50 percent of streams only for trend tests using 20 years of record. Using 20 years of record, the Type I error rates were lowest for tests of T_{Qmean}. Type II error rates (false negatives) were above 50 percent for all metrics and all periods, except T_{Qmean} with 10 years of record.

3.3. Step Trends

The difference in the value of a statistic between two periods of time was evaluated using Student's t-test (Table A2). The purpose was to evaluate the likelihood of errors in using this approach rather than quantifying the difference in the value of a statistic over time. For two consecutive samples of 5 years, both types of errors are very common. Type I errors range from 40 percent for Q_{max} to 64 percent for Q_{min}. Type II errors range from 44 percent for Q_{min} to 83 percent for T_{Qmean}.

The likelihood of either Type I or Type II errors generally decreases for larger sample sizes and longer separation of the periods being compared. For two samples of 10 years' duration separated by 10 years (i.e. the full record spans 30 years), the performance improves substantially: probabilities of a Type I error are

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40 percent for T_{Qmean}, 8 percent for Q_{min}, and 18 percent for Q_{max}. The probability of Type II error is 40 percent for T_{Qmean} and 63 percent for Q_{min}; no Type II errors occur for Q_{max}.

3.4. Same-Period, Between-Watershed Trends

Konrad (2000) explored the values of T_{Qmean} in 23 Puget Lowland watersheds with differing land use over the 10-year interval 1989-1999. As in the present analysis, the fraction of the year that daily mean discharge rate (Q_{daily}) exceeded the annual mean discharge rate (Q_{mean}) was determined for each year of record for each stream. An average value of T_{Qmean} over this period was then calculated as the average annual fraction that $Q_{daily} > Q_{mean}$. This multi-year averaging precludes this technique as a method of discerning trends over time, but it does demonstrate the responsiveness of the metric to land-use changes.

The decadal-averaged T_{Qmean} generally varied inversely with urban development among Puget Lowland streams. The mean value of T_{Qmean} for WY 1989 through 1998 for 11 urban streams (defined as a road density > 6 km per km^2) was 0.29 while it was 0.34 for 12 suburban streams (road density < 6 km per km^2). The difference is statistically significant ($p < 0.01$ using Student's t-test of samples with equal variance). "Suburban" streams had values of T_{Qmean} greater than or equal to 0.32 with the exception of Huge Creek. "Urban" streams had values of T_{Qmean} less than or equal to 0.31 with the exception of Clover Creek.

Independent of urban development, larger streams typically have more attenuated stream flow patterns than smaller streams and, as a consequence, higher values of T_{Qmean}. The decadal-averaged value of T_{Qmean} for large (drainage greater than 30 km^2) streams is 0.35, significantly greater than the mean value of 0.28 for smaller (drainage area < 30 km^2) streams. However, an analysis of the decadal-averaged values of T_{Qmean} between urban and suburban streams with drainage areas greater than 20 km^2 still indicates significantly lower values in urban streams ($p < 0.01$ based on Student's t-test of samples with unequal variance). Thus, T_{Qmean} is a reliable indicator of urban development but only for comparing watersheds with similar drainage areas (and, presumably, comparable in other physiographic factors as well).

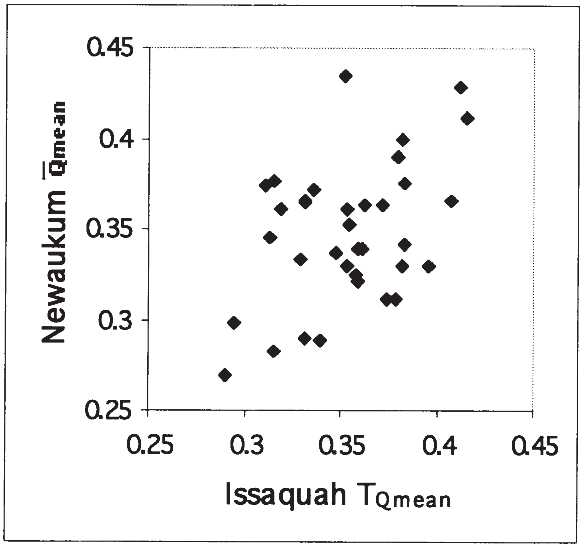

Figure 2.

An example of yearly pairs of T_{Qmean} values, plotted here for Issaquah and Newaukum creeks and displaying little relationship between the interannual variability in these two watersheds ($r^2 = 0.20$). Neither watershed has had major, systematic land-use changes over the period of simultaneous gaging (1964-1998), and neither watershed's annual values of T_{Qmean} (Table A1) show any statistically significant trend.

Although statistically significant trends do emerge from ten-year averages, year-to-year variability results in little direct relationship between different watersheds (Figure 2). In consequence, the use of a "reference" watershed to scale the current year's trend of T_{Qmean} in other watersheds, and thus to discern any temporal trends in this parameter with less than the 10- to 20-year record otherwise required (Section 3.2), does not appear warranted.

4. DISCUSSION

4.1. Record Length and Trend Identification

The hydrologic effects of urban development in western Washington are manifest as changes in annual stream flow patterns: in particular, T_{Qmean} decreases while Q_{max} increases. These trends are a consequence of the re-distribution of runoff from stormflow recessions and baseflows to stormflow. Trends in the other investigated hydrologic parameters, Q_{mean} and Q_{min}, were not consistently observed in urban streams and, in fact, were observed in some suburban and rural streams where watershed-scale land-use changes have not been dramatic. Although urban development may had an influence on Q_{mean} or Q_{min} in some streams, there are no consistent relationships observed.

The natural variability of stream flow is so great that hydrologic trends due to anthropogenic influences are difficult to detect reliably. Particularly for gage records briefer than about two decades, both parametric and nonparametric statistical tests demonstrate relatively high rates of errors. These errors include both the identification of a trend where none exists (Type I error) and *not* identifying a trend where a longer record would show that in fact one *does* exist (Type II error). As a result, any conclusions about hydrologic trends based on short periods of record (<10 to 20 years, at minimum) should be tentative and may not apply to periods before or after the one under investigation.

4.2. Implications for Watershed Monitoring

This analysis of the hydrologic response of watersheds to urbanization holds several implications for watershed monitoring. First, it affirms the underlying premise that evaluating the success of hydrologic mitigation is important—changes are real, and they correlate with (and probably are largely responsible for) well-documented declines in the health of aquatic ecosystems in urban watersheds. Second, hydrologic differences between watersheds can be described by hydrologic metrics, particularly T_{Qmean}, that are easily calculated from a daily or hourly discharge record and that capture the influence of urban development far better than traditional measures of streamflow. Finally, the annual variability of rainfall is so great that "trend monitoring" is possible and defensible, but also slow—even the

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large hydrologic influence of urban development will require a gage record that spans 20 years or more in order to recognize trends or to assert their absence.

4.3. Recommendations for Gage Sites

Gage sites suitable for evaluating the hydrologic influence of urban development will have the following general characteristics:

- *Existing or anticipated urban development:* At this time, our analysis does not support the establishment of a network of "control" sites for discerning trends in hydrologic change. Thus sites should be chosen where urban development is anticipated in the contributing watershed.
- *Minimum watershed size:* Perennial stream flow is needed; based on previously compiled data, this requires a contributing watershed area of at least 1 to 10 km^2 (0.4-4 mi^2) depending on specific conditions. If the site *is* perennial, trends can be identified—there is no other apparent minimum size limitation.
- *Maximum watershed size:* The hydrologic effects of urban development should become increasingly difficult to recognize in progressively larger watersheds. This is due in part because urbanization is less likely to affect large percentages of large watersheds, and in part because the types of hydrologic changes resulting from changes in infiltration and channeled flow become progressively less influential in the hydrographs of increasingly large rivers. Based on our existing data set, the gages at Soos and Issaquah creeks are probably "too large" to be useful for trend determination (171 and 145 km^2), Newaukum Creek may be too large (70 km^2), and Mercer Creek is clearly *not* too large (31 km^2). A maximum size of 40 km^2 (16 mi^2) is suggested as a working limit, given the present analysis.
- *Length of Record:* Because a minimum of one decade is necessary to detect strong trends and two decades is preferable in most cases, the most suitable sites will be those where a gage record already exists. A discontinued gage site can provide data that is nearly as useful as one in continuous operation, as long as the site had at least several years of previous data and can be reoccupied, and a new regime of data-collection can be initiated.

These four criteria can be readily evaluated from a tabulated list of gage sites and a simple map. One additional set of criteria, however, is warranted as part of making a final selection of gage sites:

- *Watershed sensitivity:* As a generic goal, monitored watersheds should be "sensitive" to the changes imposed by urban development. This sensitivity is expressed by (1) predominant soils, where non-infiltrative deposits or their overlying soil (*e.g.*, glacial till and Alderwood soil) will respond more clearly to any hydrologic expression of urbanization than more infiltrative deposits that may mask the in-channel effects of increased runoff; and (2) channel-network topography and morphometry, where steep and equant (*i.e.* width = length) basins with a high density of channels should be more responsive to changes than flat, elongated basins with a relatively low aggregate length of channels for the size of the watershed. Obvious hydraulic controls, such as a large lake between the area of anticipated development and the gage site, will also compromise sensitivity.

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HYDROLOGIC TRENDS AND HYDROLOGIC MONITORING IN URBANIZING STREAMS OF WESTERN WASHINGTON

(from page 8

APPENDIX

		Q_{mean} (m^3/s)	T_{Qmean}	Q_{min} (m^3/s)	Q_{max} (m^3/s)
Mercer Creek	Years	43	43	43	43
	Median	0.63	0.29	0.17	7.9
	Average	0.64	0.29	0.17	9.49
	CV	0.21	0.14	0.23	0.57
	p-values for Kendall's t (two-sided)	0.408	**<0.001(-)**	**<0.001(+)**	**<0.001(+)**
Swamp Creek	Years	24	24	24	24
	Median	0.93	0.32	0.13	13.42
	Average	0.96	0.31	0.13	13.46
	CV	0.21	0.11	0.2	0.38
	p-values	0.366	0.3	**0.004(+)**	0.25
Newaukum Creek	Years	52	52	52	55
	Median	1.7	0.35	0.41	17.11
	Average	1.7	0.35	0.42	21.7
	CV	0.24	0.1	0.22	0.75
	p-values	**0.088(-)**	0.523	**<0.001(-)**	**0.0912(-)**
May Creek	Years	16	16	16	28
	Median	0.65	0.34	0.09	6.2
	Average	0.66	0.33	0.09	8.08
	CV	0.27	0.11	0.14	0.98
	p-values	0.32	0.55	0.45	0.55
Leach Creek	Years	38	38	38	39
	Median	0.13	0.24	0.04	1.84
	Average	0.13	0.25	0.04	2.43
	CV	0.25	0.16	0.33	0.95
	p-values	**<0.001(+)**	**0.112(-)**	0.333	**<0.001(+)**
Juanita Creek	Years	24	24	24	24
	Median	0.31	0.3	0.08	3.63
	Average	0.31	0.3	0.07	5.15
	CV	0.21	0.11	0.2	0.38
	p-values	0.254	**0.029(-)**	0.655	**0.002(+)**
Big Beef Creek	Years	16	16	16	16
	Median	1.28	0.28	0.1	17.8
	Average	1.22	0.28	0.1	19.72
	CV	0.35	0.21	0.21	0.56
	p-values	0.28	0.653	**0.115(+)**	0.418
Huge Creek	Years	44	44	44	43
	Median	0.31	0.28	0.11	3.63
	Average	0.31	0.27	0.11	4.8
	CV	0.28	0.18	0.15	0.98
	p-values	0.887	**0.108(-)**	**0.086(-)**	0.645
Soos Creek	Years	39	39	39	39
	Median	3.52	0.4	0.72	20.42
	Average	3.49	0.39	0.72	24.06
	CV	0.27	0.1	0.2	0.88
	p-values	0.762	0.726	0.971	0.603
Issaquah Creek	Years	35	35	35	36
	Median	3.78	0.36	0.68	46.3
	Average	3.77	0.35	0.68	45.22
	CV	0.26	0.09	0.22	0.44
	p-values	**0.063(-)**	0.67	**0.001(-)**	0.513

Table A1.

Results of trend analysis over period of record using Kendall's t test; statistically significant values are shaded (with the direction of the trend noted).

Kendall's t test	T_{Qmean}	Q_{min}	Q_{max}
5-YEAR PERIODS			
Type I error	80%	60%	60%
Type II error	100%	50%	100%
10-YEAR PERIODS			
Type I error	80%	100%	100%
Type II error	none	50%	67%
20-YEAR PERIODS			
Type I error	20%	40%	40%
Type II error	100%	50%	100%

Student's t-test	T_{Qmean}	Q_{min}	Q_{max}
Comparison of 5-year means, consecutive periods:			
Type I error	33%	50%	50%
Type II error	75%	17%	100%
Comparison of 5-year means separated by 5-year periods:			
Type I error	67%	50%	25%
Type II error	75%	17%	83%
Comparison of 10-year means, consecutive periods:			
Type I error	67%	50%	50%
Type II error	25%	17%	83%
Comparison of 10-year means separated by 5-year periods:			
Type I error	33%	50%	50%
Type II error	50%	33%	83%

Table A2.

Percentage of streams where trend tests for a subset period produced erroneous results.

- Type I errors: test of a subset period produced false positive compared to the period of record (*i.e.* trend predicted where none exists)
- Type II errors: test of subset period produced false negatives compared to the period of record (*i.e.* no trend recognized where one does exist)

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HYDROLOGIC TRENDS AND HYDROLOGIC MONITORING IN URBANIZING STREAMS OF WESTERN WASHINGTON

(from page 9)

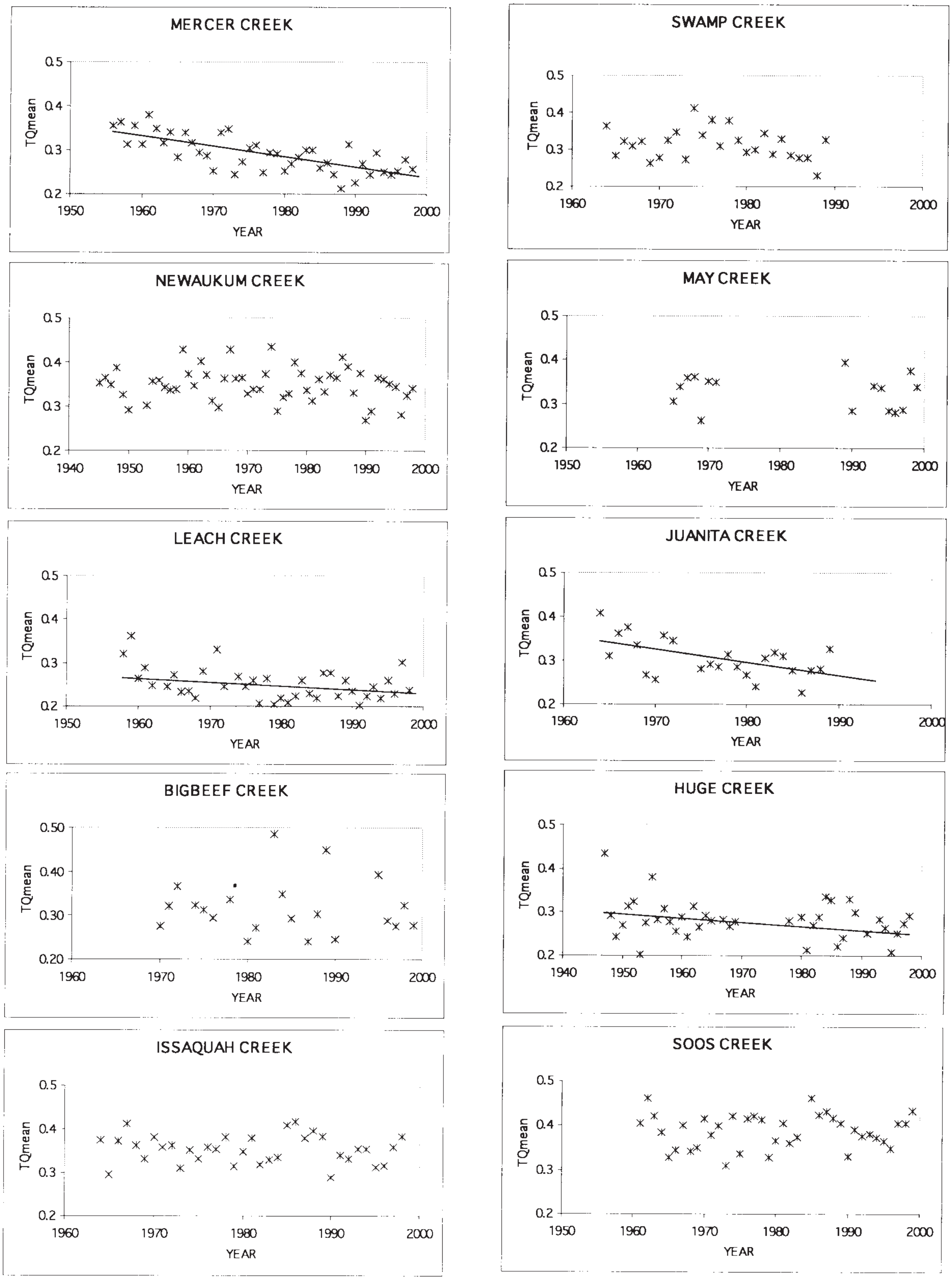

Figure A1.

Graphs of all calculated T_{Qmean} values for all streams, all years. Trend lines are plotted only for those with statistical significance (Table A1).

Continued on page 11

HYDROLOGIC TRENDS AND HYDROLOGIC MONITORING IN URBANIZING STREAMS OF WESTERN WASHINGTON

(from page 10)

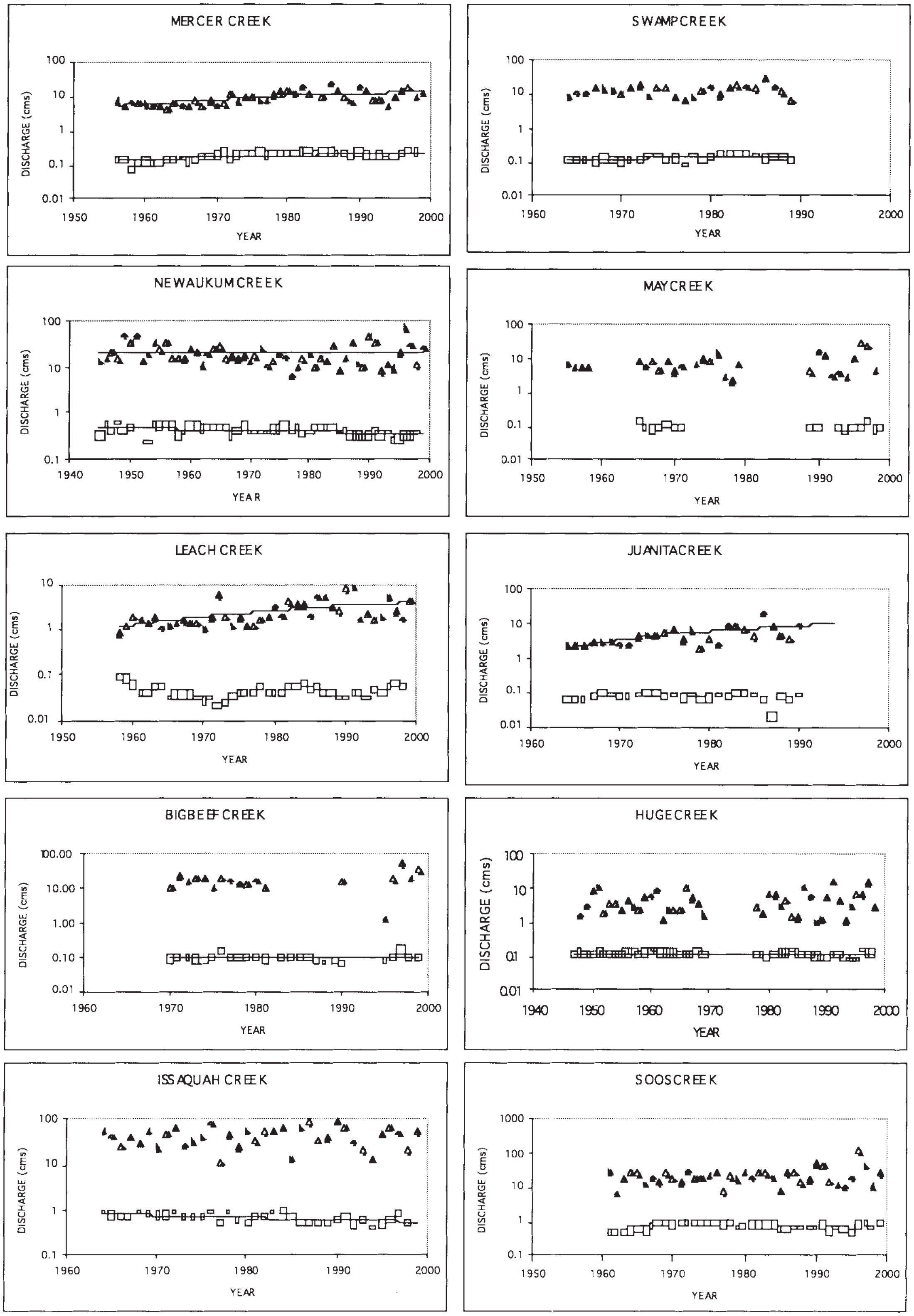

Figure A2.

Graphs of all values of Q_{min} (circles) and Q_{max} (triangles) for all streams, all years. Trend lines are plotted only for those with statistical significance (Table A1).

Publication update of current projects at the Center (with dates of Newsletter articles and available Center publications)

Project	Newsletter Issue	Center Publication
LAND COVER AND IMPERVIOUSNESS		
Landsat land cover interpretation	Sp 99, F 00	CUWRM web rpt. & data
Infiltrative parking lot surfaces	W 96, F 96	K19
The impact of urban patterns on ecosystem dynamics	Su 01	
GEOLOGY AND SOILS		
Puget Lowland geology and geologic hazards	Sp 97, Su 98	linked web site
STREAMS		
Urban stream rehabilitation:	Su 98, Sp 01	Final report (on web)
Riparian buffers in urban watersheds	W 97	CUWRM web report
Effectiveness of LWD in rehabilitation projects	W 00	K25
Sediment budget of mixed-use watershed	F 99	K23
Rates of stream channel restabilization	Su 99	K24
Urbanization effects on stream biology	Sp 00	K26
Metrics of hydrologic change from urbanization	F 00, F 01	
Urban Planned Development monitoring:	F 99	CUWRM web report
Relationship of turbidity to total suspended solids		
Monitoring of ephemeral streams		
Stream habitat assessment protocols	W 99	E17 (on CUWRM web)
Remote sensing of stream temperature	W 00	
Regional, synchronous stream temperature survey	Su 98, F 98	CUWRM web data
WATER QUALITY/CHEMISTRY		
Water-quality effects of road ditches and swales	F 99, F 00, W 01	G15 (on CUWRM web)
Urban stormwater management evaluation	F 99	
Highway stormwater treatment testing	W 00, F 00	G14 (on CUWRM web)
WATER USE, REUSE, AND GROUNDWATER		
Numerical groundwater modeling of the Duwamish		CUWRM web report
Review of water reuse case studies	Su 01	L1 (on CUWRM web)
On-site runoff mitigation by reuse of rainwater	W 01	
REFERENCES		
Urban Issues Library	F 99	On CUWRM web site
Salmon in the City conference proceedings		On CUWRM web site

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February 11–13, 2002 • Lacey

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