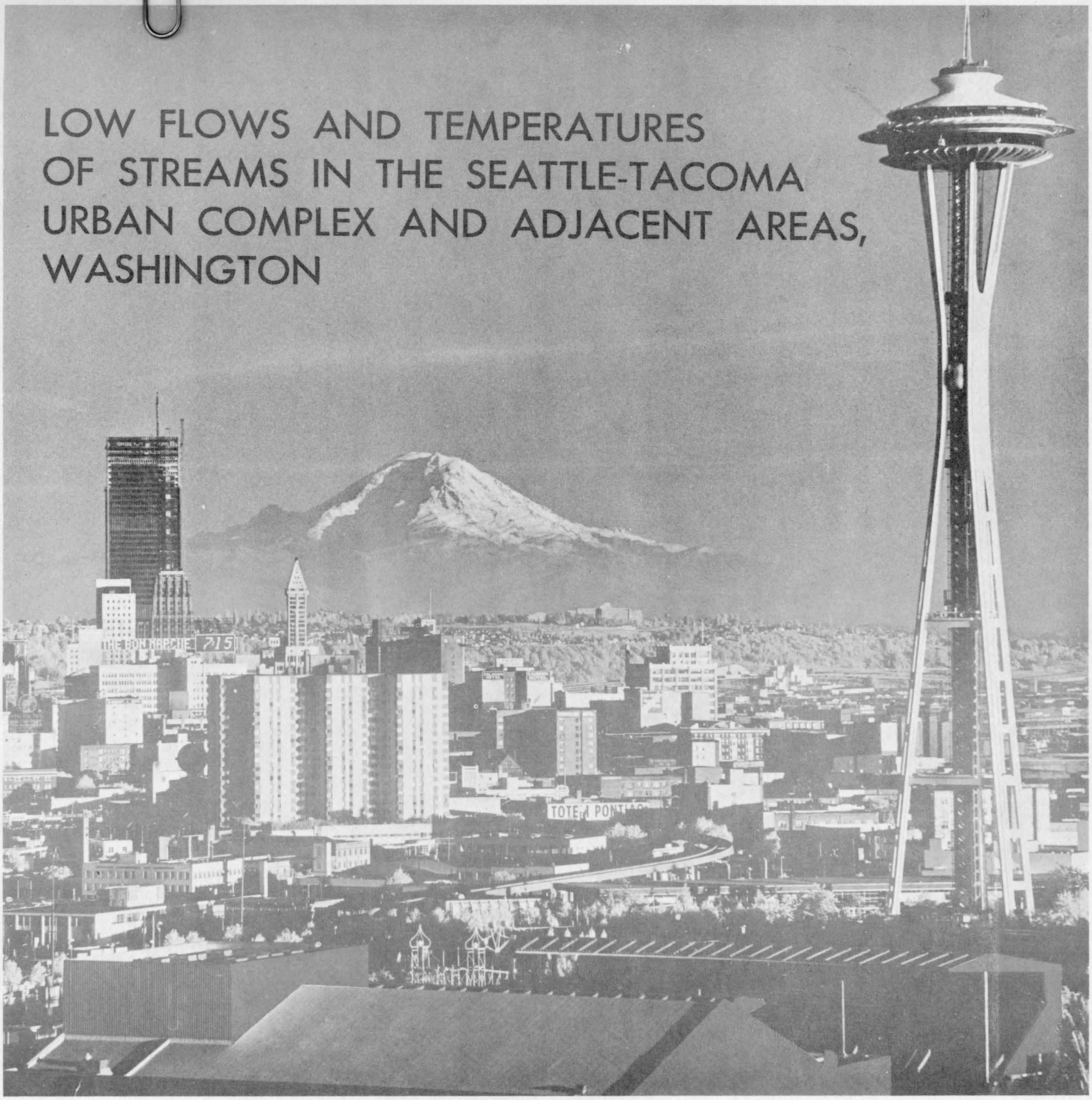
LOW FLOWS AND TEMPERATURES OF STREAMS IN THE SEATTLE-TACOMA URBAN COMPLEX AND ADJACENT AREAS, WASHINGTON



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By
Frank F. T. Hidaka 1918

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LOW FLOWS AND TEMPERATURES OF STREAMS IN THE SEATTLE-TACOMA URBAN COMPLEX AND ADJACENT AREAS, WASHINGTON

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INTRODUCTION

Data on the minimum flows of streams and water temperature are necessary for the proper planning and development of the water resources of urban Seattle-Tacoma and adjacent areas. The data on low flows are needed for such purposes as (1) designing and operating municipal and industrial water-supply systems; (2) classifying streams as to their potential for waste disposal; (3) defining the amount of water available for irrigation, for maintaining streamflow as required by law or agreement, and for fish propagation; and (4) designing water-storage facilities. Data on stream temperatures are important to many water users because of the many biological, chemical, and physical properties of water that are dependent on temperature. Agricultural and domestic users as well as municipal, industrial and fishery agencies are concerned with water temperatures.

In this report, low-flow data are accompanied by information on seasonal variations in water temperatures at sites selected as representing regional stream-temperature patterns. Because low flows and high water temperatures commonly occur together, they may impose constraints on various uses of the region's streams. The following discussion deals first with low-flow trends in the region, then with stream temperatures, and finally with some of the resulting constraints.

LOW FLOWS

Variation in Time

The average annual runoff of streams in the Seattle-Tacoma region is large--13,000 mgd (million gallons per day) discharging to Puget Sound--but, because of annual seasonal variations, streamflow decreases to less than one-fifth this amount--2,300 mgd--during the late summer and early fall. This seasonal decrease in streamflow is an important factor in water-resources planning and development; the minimum flow represents the dependable amount of water available without storage.

The low flows of major streams in the Seattle-Tacoma area are shown on the accompanying plate. The low-flow value illustrated represents the lowest average daily flow for a 7-day period that can be expected on an average of once every 2 years. Low-flow data for the principal streams in the study area are shown in table 1. In addition to the 2-year or median 7-day low flow, 7-day low flows with recurrence intervals up to 30 years are listed in the table.

Low flows of streams vary from year to year. The variability of the low flows, as indicated by the annual 7-day minimum discharges of three selected streams in the study area, is shown in the three graphs on the plate. The three streams drain basins of approximately the same size, but comparison of the curves shows large differences between the streams in their average low flows and variations of low flows from year to year.

Factors Affecting Low Flows

The quantity and distribution of low flows are determined by the climatic and physical environments and by changes in those environments resulting from man's activities.

The principal climatic characteristics that influence low flow are precipitation and temperature. Precipitation is the ultimate source of all streamflow. Temperature affects both water loss by evaporation and transpiration and the time distribution of low flow. For example, subfreezing temperatures cause storage of water as ice and snow in high-altitude basins, and occurrence of low flows during the winter months. Then, during the spring and summer, melt water from glaciers and snowfields sustains low flows. The flow of streams in the lowlands, which do not benefit from such storage, may become critically low during the dry summer months when water is most needed for many uses.

TABLE 1.--Seven-day low-flow-frequency data at selected sites in the Seattle-Tacoma urban complex and adjacent areas

Station no.	Stream	Stream discharge (mgd) for indicated recurrence interval				
		2 yr	5 yr	10 yr	20 yr	30 yr
12080000	Deschutes River near Olympia	62	55	52	48	46
12084000	Nisqually River near Alder	226	187	170	155	149
12089500	Nisqually River at McKenna	108	47	26	16	12
12093500	Puyallup River near Orting	165	136	121	110	105
12098500	White River near Buckley	310	252	220	194	181
12101500	Puyallup River at Puyallup	762	652	588	530	497
12106500	Green River near Palmer	97	78	69	65	61
12113350	Green River at Tukwila	142	109	91	78	71
12117500	Cedar River near Landsburg	168	136	119	110	103
12119000	Cedar River at Renton	65	36	26	19	15
12126500	Sammamish River at Bothell	62	50	46	43	41
12134500	Skykomish River near Gold Bar	478	368	317	278	252
12149000	Snoqualmie River near Carnation	413	323	291	274	265

Physical characteristics such as basin size, topography, geology, and vegetation also influence low flows. In addition, low flows are affected by manmade changes--structures on the land surface and in stream channels that accompany urbanization and the development and use of water. Many of these factors are closely interrelated and their individual effects are often difficult to isolate.

Geologic conditions have a major influence on the characteristics of low flows in the Seattle-Tacoma urban and adjacent areas, particularly in those lowland basins underlain by highly permeable glacial drift. The glacial drift serves as a natural storage reservoir for a significant part of the winter precipitation; this ground-water storage then becomes the major, and for some periods the only, source of streamflow during the dry months of late summer and early fall.

It should be noted that the low flows of these lowland streams are less than those of the higher altitude streams, this is not due to less favorable geologic conditions in the lowlands, but, rather, to the contribution from melting snow and ice in the mountains east of the study area during the summer months. In fact, were it not for the addition of melt water from glaciers and snowfields during the summer low-flow period, these mountain streams would have relatively small low flows; ground-water inflow from storage in the dense, poorly permeable bedrock underlying these mountain watersheds is generally insignificant.

Although the effects of urbanization are most noticeable in storm runoff, low flows also are affected. The paving of streets and parking lots and the erection of buildings effectively seal large areas. Therefore, infiltration of precipitation and recharge of the ground-water reservoir are effectively reduced. In turn, ground-water discharge to the streams is reduced. On the other hand, low flows are frequently increased where sewage effluents are discharged into streams (Spieker, 1970).

Regulation of streamflow for municipal and industrial supply, power generation, flood control, and irrigation modifies the low flows of streams. Diversions for irrigation and municipal supply usually reduce low flows; in some cases, diversions are severe and result in effects that are detrimental to fish life and other downstream uses. Natural low flows can be either augmented or decreased and the quality may be changed by the procedures used to regulate the releases from reservoirs. Reservoirs used for flood control and municipal supply usually result in increased low flows because water is stored during periods of high runoff and released gradually after the high-water period. Augmentation of low flows increases the quantity of water available downstream for dilution of waste discharges, irrigation and municipal supplies, and improves conditions for optimum propagation of fish.

Prospects for the Future

Low flows of major streams in the area are sufficient to meet immediate demands without additional storage even though only about 20 percent of the average annual discharge is available. However, the problem of allocation of these flows for various uses will intensify with increased urban growth in the area.

Competing demands for the available water will require major management decisions. Augmentation of low flows through storage undoubtedly will be necessary where local concentrations of urban or industrial growth place heavy demands upon the local water environment. Regional planning can anticipate these demands, but sound management of the water resource by regional and local authorities must be effected to prevent deterioration of the water resources.

STREAM TEMPERATURES

Significance for Various Uses

Water temperature has considerable significance for many uses. For public water supplies, desirable temperatures generally should not exceed 10.0°C (Celsius), or 50°F. Where temperatures exceed 18.3°C (65°F) tastes and odors may become noticeable (Everts, 1963, p. 2). Low water temperatures also are desirable for many industrial uses, especially for cooling. The water used for cooling and for power generation in fossil-fuel steam and nuclear-reactor plants is usually returned at a warmer temperature to the stream, resulting in "thermal loading." This in turn causes a reduction of the DO (dissolved oxygen) concentration in the water, and the combination of both factors may adversely affect downstream aquatic life. The effects of thermal loading reach a maximum during low-flow periods when the volume of diluting water is small and natural stream temperatures already tend to be high.

Fisheries agencies are vitally interested in stream temperature because fish do not maintain fixed body temperatures. Thus, any increase in water temperature increases the biological activity of fish, and hence their energy consumption--and oxygen utilization. This, coupled with the thermal reduction of oxygen level, may result in insufficient oxygen concentrations in the stream to maintain some species of fish. Selection of hatchery sites and development and preservation of spawning and rearing grounds are critically dependent on the temperature of the water.

The seasonal variations of monthly maximum, minimum, and mean stream temperatures at selected locations in the study area are shown by the graphs at the numbered sites on the plate. Table 2 shows the mean annual temperature and the range of the monthly mean water temperatures. The cyclic patterns closely follow the pattern of air temperatures; stream temperatures are lowest during the winter, usually in January, and are highest during the summer, usually in July. As noted, the higher temperatures commonly occur during the low-flow periods.

Factors Affecting Stream Temperatures

The natural rise and fall of stream temperatures are governed by a number of climatic and physical factors. Climatic factors include solar radiation, air temperature, wind velocity, and vapor pressure. Physical factors include water-surface area, water depth, rate of water exchange, shading from vegetation and landmasses, impurities in the water, and surface and subsurface inflow. The most important factor is solar radiation. Stream temperatures are at maximum in the summer, when solar radiation is at a maximum and at a minimum in the winter when solar radiation is at a minimum.

Various uses of water by man influence stream temperatures. Thermal discharges have already been mentioned. Water diverted through a municipal water-supply system and subsequently discharged through a sewerage system may cause a significant rise

TABLE 2.--Temperature characteristics of selected streams

Site number on plate	Station number	Stream	Mean temperature °C	Mean temperature °F	Amplitude[a] °C	Amplitude[a] °F
1	12079000	Deschutes River near Rainier	10.0	50	11.1	20
2	12091100	Flett Creek at Tacoma	11.7	53	6.1	11
3	12093500	Puyallup River near Orting	7.8	46	6.7	12
4	12117000	Taylor Creek near Selleck	7.8	46	6.7	12
5	12126000	North Creek near Bothell	10.6	51	11.1	20
6	12137500	Sultan River near Startup	7.2	45	8.3	15
7	12157000	Quilceda Creek near Marysville	8.3	47	7.8	14

[a] Range between the coolest and warmest monthly mean water temperature.

in temperature of the receiving water body. Oxidation of the waste materials in polluted waters generates heat and may increase water temperatures. Impoundment of water in reservoirs generally changes the water-temperature regimen downstream. The various temperature effects on impounded water depend on volume of water stored, surface area, depth of reservoir, temperature of inflow water, and depth and rate at which water is withdrawn.

The White River--A Man-Affected Stream

An example of the effects of man's activities on the stream-temperature regimen is shown by the pattern of temperature changes in the White River, a tributary of the Puyallup River. Mean annual stream temperature for six sites in the White River basin and for the Puyallup River below the mouth of White River are presented in table 3. The listing of sites in downstream order shows clearly the pattern of changes that occur in stream temperatures in the region. Because the White River originates at a glacier, the stream temperature close to the source in Mount Rainier National Park is cool--4.4°C (40°F). By the time the water reaches Greenwater, the temperature has warmed to 6.1°C (43°F). Downstream from that site, the White River receives inflow from Greenwater River which has a temperature of 6.7°C (44°F) and the total flow then goes to Mud Mountain Dam, where water is stored during parts of the year. Below the dam, near Buckley, the water has warmed to 7.2°C (45°F). A large part of the flow then is diverted from White River into a canal to be stored in Lake Tapps for power generation. Near Sumner, below the diversion, the average water temperature has increased 4.5°C (8°F), to 11.7°C (53°F). Cooler water--10.6°C (51°F)--from Lake Tapps is returned to the river after passing through the Dieringer powerplant. White River then joins the Puyallup River and the water temperature is reduced to 9.4°C (49°F) by mixing with the colder water from the Puyallup River.

TABLE 3.--Mean annual stream temperatures at sites in the White and Puyallup River basins

Station no.	Stream	Mean annual stream temperature °C	Mean annual stream temperature °F
12096600	White River near Greenwater	4.4	40
12097000	White River at Greenwater	6.1	43
12097500	Greenwater River at Greenwater	6.7	44
12098500	White River near Buckley	7.2	45
12100500	White River near Sumner	11.7	53
12101100	Lake Tapps diversion at Dieringer	10.6	51
12101500	Puyallup River at Puyallup	9.4	49

CONSTRAINTS

Water-resources planning must take into consideration the consequences that will accompany any man-caused changes in streamflow and temperature. Only when regional water uses are defined and priorities established can proper decisions be made as to what changes can and cannot be tolerated.

As an example, a decision to reserve a stream, or reach of a stream, for fish propagation calls for knowledge of low flows and water temperatures, as well as other characteristics of the stream. Then controls over those characteristics can be designed to meet the selected needs on a continuing basis. On the other hand, a deliberate decision to use a reach of stream as a sink for thermal wastes may preclude use of that stream for other purposes, such as domestic supply.

Man has considerable capacity to regulate the volume of streamflow by controlling storage and release of water. With somewhat greater difficulty, he can modify stream temperature by storage, mixing, and designed releases of water from impoundments. But each use must be defined and each criterion specified before a plan of management can be made. There are virtually no universal design methods--each stream will require individualized analysis of its flow characteristics and geographic setting before plans are made for designing facilities for controlling its discharge and temperature.

SELECTED REFERENCES

Collings, M. R., 1969, Temperature analysis of a stream, in Geological Survey research, 1969: U.S. Geol. Survey Prof. Paper 650-B, p. B174-B180.

Collings, M. R., and Higgins, G. T., 1972, Stream temperatures in Washington State: U.S. Geol. Survey Hydrol. Inv. Atlas HA-385 (in press).

Everts, C. M., 1963, Temperature as a water quality parameter, in Water temperature - influences, effects, and control: U.S. Pacific Northwest Water Laboratory, Pacific Northwest Symposium on Water Pollution Research, 12th, Corvallis [Oregon] Proc., p. 2-26.

Griffin, W. C., Sceva, J. E., Swenson, H. A., and Mundorff, J. J., 1962, Water resources of the Tacoma area, Washington: U.S. Geol. Survey Water-Supply Paper 1499-B, 98 p.

Huntting, M. T., Bennett, W. A. G., Livingston, V. E., Jr., and Moen, W. S., 1961, Geologic map of Washington: Washington Div. Mines and Geology.

Moore, A. M., 1967, Correlation and analysis of water-temperature data for Oregon streams: U.S. Geol. Survey Water-Supply Paper 1819-K, 53 p.

Puget Sound Task Force, Hydrologic Studies Technical Committee, 1970, Hydrology and natural environment, appendix III, of Comprehensive study of water and related land sources, Puget Sound and adjacent water, State of Washington: Pacific Northwest River Basins Comm., Vancouver, Wash., 205 p.

Richardson, Donald, Bingham, J. W., and Madison, R. J., 1968, Water resources of King County, Washington: U.S. Geol. Survey Water-Supply Paper 1852, 74 p.

Spieker, A. M., 1969, Some observations on streamflow and water quality on an urban environment: U.S. Geol. Survey open-file report, 21 p.

-----1970, Water in urban planning, Salt Creek basin, Illinois: U.S. Geol. Survey Water-Supply Paper 2002, 147 p.

U.S. Weather Bureau, 1967, Climatological data, Washington annual summaries, 1967: U.S. Weather Bur., v. 71, no. 13.

Ward, J. C., 1963, Annual variation of stream temperature: Jour. Sanitary Engineering Div., Am. Soc. Civil Engineers, v. 89, SA6, Proc., Dec. 1963, p. 3710 (1-16).