Section 3.3 Contents

3.3 Studies, Analyses, and Workshops

3.3.1 Introduction

In preparing this HCP, the City conducted or sponsored a variety of specific studies, analyses, and workshops. Some of these efforts were initiated before preparation of this HCP began in 1993, and some were completed specifically for the HCP. These efforts include:

- Studies of the relationship of instream flows and fish habitats, conducted cooperatively with state and federal agencies and the Muckleshoot Indian Tribe;
- A watershed assessment patterned after the state watershed analysis process to determine the condition of the watershed, identify factors causing problems, and identify opportunities for restoration;
- A series of workshops with regional scientists to discuss conservation strategies for restoring old-growth forest habitat; designing an Ecological Reserve and developing approaches to timber harvest in the municipal watershed that would sustain the forest ecosystem; and developing mitigation and conservation strategies for bull trout that use the reservoir complex and for anadromous salmonids blocked from passage into the municipal watershed by the Landsburg Diversion Dam;
- A risk assessment performed to determine what species and numbers of fish could be passed above the Landsburg water intake without jeopardizing drinking water quality;
- A pilot aquatic monitoring project, designed to develop and evaluate methods for using benthic organisms in streams to monitor stream habitat health; and
- Forest inventory and modeling used to project future forested habitat and potential revenues from timber harvest.

3.3.2 Instream Flow Studies

GENERAL BACKGROUND

Over the past 30 years, there have been many studies of Cedar River fisheries, basin hydrology, and instream flows. The studies were funded or conducted by the City, the WDF, ACOE, WDOE, USGS, Muckleshoot Indian Tribe, and the University of Washington FRI. In addition, several M.S. theses and Ph.D. dissertations have been written on many aspects of Cedar River fisheries.

Of particular importance to the management of Cedar River water resources have been studies related to instream flows. Instream flow is the volume of water flowing through the stream channel per unit time, generally measured in cubic feet per second (cfs). Instream flow variations affect a number of aspects of the river, including fish and wildlife, recreation and aesthetics, and the maintenance of water quality, channel morphology, and riparian vegetation. If managed properly, instream flows can provide beneficial uses and functions for these varied aspects.

Factors influencing or controlling instream flows in natural rivers differ in some distinct ways from those in regulated systems. Instream flows in natural rivers are determined directly by precipitation levels, watershed characteristics, and other hydrologic variables. Instream flows of regulated rivers respond not only to precipitation and watershed characteristics but also to water storage, diversion, and release operations to meet particular water project management objectives, such as flood control, power generation, and water supply.

Instream flow and related studies attempt to provide natural resource and water project managers the scientific information necessary to appropriately allocate stream flow in regulated or diverted rivers to protect or enhance beneficial uses and functions. The earliest instream flow studies of the Cedar River that related salmon production to stream flow were conducted by the USGS and the WDF between 1967 and 1969 (Collings et al. 1970). The purpose of the study was to determine the appropriate spawning discharges for coho, chinook, and sockeye salmon in the fall. Results of these early studies indicated that peak spawning discharges measured at Renton for sockeye ranged from 240 cfs to 510 cfs and averaged 422 cfs. Studies of rearing habitat indicated a flow of between 50 and 100 cfs was appropriate (Collings et al. 1970). Based on study results of the USGS and the WDFW, instream flows (measured at the Renton USGS gage) were first set for the Cedar River in 1971 by WDOE at the request of the WDF (RCW 90.54).

Soon after 1971, the City and the ACOE determined that standard operations could not be sustained under the established minimum instream flow levels. The City then contracted the FRI to study the relationship between discharge and sockeye production in the Cedar River. Concurrently, studies by the ACOE indicated an increasing demand for lockage, a demand that would not be met with summer minimum flows of 75 cfs from the Cedar River.

Between 1972 and 1980, the FRI conducted numerous studies on the in-river biology and stream flow requirements of Cedar River sockeye. One finding was that maximum available spawning habitat for 11 Cedar River study reaches was achieved at a discharge 250 cfs measured at the Renton gage (Stober and Greybill 1974).

In addition, Stober et al. (1974, 1979, 1980) studied several factors that affect reproductive success of Cedar River sockeye. These included instream flows, effects of flood flows, and egg-to-fry survival. According to Stober, these studies indicated that the number of redds could hypothetically be increased by ramping the flow up iteratively. It was argued that this procedure would provide center channel habitat at lower flows and recruit additional habitat as the stream flow was increased over time, thus reducing density-dependent mortality of eggs as a result of redd superimposition by several spawning females. These studies also indicated that major flood events are a primary factor in limiting egg-to-fry survival in the Cedar River.

Miller (1976) studied the relationship between sockeye production and discharge in the Cedar River. Data used in his calculations were primarily from the literature. According to Miller, flows during spawning have a relatively small effect on fish production unless they are reduced to very low levels, which would be expected to occur very rarely. Miller also postulated that flood flows in the Cedar River have a very significant effect on fish production. In later studies, Ames (1983) and Thorne and Ames (1987) found a strong negative correlation between short-term, high river flows and survival to pre-smolt of sockeye from the Cedar River.

Differences in results between the USGS-WDF studies and the FRI studies led to controversy over which of the two study programs should be used as a basis for setting instream flows. In October 1976, the Cedar River Ad Hoc Water Resources Management Committee (Ad Hoc Committee) was formed to seek solutions for the problems surrounding the use of Cedar River waters (WDOE 1979). Between 1976 and 1979 there were numerous meetings and negotiations between the City, FRI, WDF, WDOE, ACOE, and the Ad Hoc Committee to resolve the instream flow issue. These exchanges did not resolve the instream flow issue for the Cedar River (WDOE 1979). By 1979, WDOE had decided that there would never be an agreement between the two study programs because each had different underlying purposes and different methodologies.

In early 1979, WDOE initiated the Western Washington Instream Resources Protection Program (WWIRPP) to establish instream flows in sufficient quantities to support food and game fish populations in western Washington streams. As a result of the WWIRPP, WDOE repealed Cedar River minimum flows established in 1971 and adopted adjusted normal year and critical year flow regimes (WAC 174-30-020; WDOE 1979). However, as acknowledged by WDOE, these new flows were not binding on the City (see Section 2.2.5).

In 1986, the City initiated the formation of the Cedar River Instream Flow Committee (the Committee) to develop an instream flow study program for the Cedar River that was based on current scientific methods and was conducted in full collaboration with state, federal, and Tribal scientists. The Committee benefited from the advances in instream flow science and computer technology since the WWIRPP and earlier instream flow studies. Committee members included the City, WDFW, WDOE, ACOE, USFWS, NMFS, and the Tribe. The Committee recommended that the widely used USFWS Instream Flow Incremental Method (IFIM) and supporting analyses be conducted.

The difference between previous methods and the IFIM was the IFIM's greater requirements for detailed site specific geomorphological, hydraulic, and habitat utilization data. The IFIM is discussed briefly in the subsection entitled "Overview of Study Methods" below.

The primary objectives of the instream flow and habitat utilization studies set by the Committee were to:

(1) Develop Weighted Useable Area for selected species and life stages for specified reaches of the Cedar River;

(2) Develop site-specific habitat utilization criteria for selected species and life stages;

(3) Conduct effective spawning habitat analyses for sockeye and steelhead;

(4) Conduct cumulative spawning habitat analyses in order to evaluate the feasibility of maximizing sockeye spawning potential; and

(5) Investigate flood scour impacts on sockeye redds.

Through an interview process conducted by the Committee in November 1986, Cascades Environmental Services, Inc. of Bellingham, Washington was selected to conduct the required studies. Instream flow and related studies were conducted in full collaboration and coordination with the Committee between 1986 and 1991. During this time, the Committee and various subcommittees met more than 20 times, including several field visits, to jointly develop and implement the study program. The Committee met at least an additional 27 times in the analysis phase of the program between 1991 and January 31, 1996. Much of this analytical work related to the development and evaluation of instream flow proposals during multiparty negotiations, which began in 1993. The contribution and frequency of attendance of each representative was high throughout the duration of the Committee's existence.

Draft and final reports titled *Cedar River Instream Flow and Salmonid Habitat Utilization Study* were submitted to the Committee in March 1990 and October 1991, respectively. With revisions to the draft, the final report was received by the Committee as an accurate representation of study program methods and results. Complete documentation of consultation with the Committee regarding study design, implementation, and analyses between 1986 and 1991 is included as an appendix to the final report. Documentation of consultation for these meetings is available upon request.

STUDY AREA BOUNDARIES

All studies were conducted between RM 1.7, which is the lower-most extent of the natural river, upstream 32.5 miles to the upper-most range of historic anadromous fish use at RM 34.2, at the base of Lower Cedar Falls. Within these boundaries, the Cedar River was segmented into four study areas. The major distinctions between each study area include existing and potential species utilization, flow control by diversion or storage, and hydrology. The study areas and their distinguishing characteristics are described below. *Note that the terms "lower" and "upper" used in this subsection for reaches of the Cedar River refer specifically to this study, and their use here does not reflect divisions of the river system for this HCP.*

- *Lower Cedar River Study Area*: This reach extends from RM 1.7 to the City's Landsburg Diversion Dam at RM 21.8. It is distinct from the three areas upstream in that it is accessible to all anadromous fish and it is the reach affected by water withdrawal at Landsburg. This study area is further divided into 3 study reaches.

- *Upper Cedar River Study Area*: This reach extends from RM 22.1 (the upper end of the Landsburg Diversion Dam forebay) upstream to a point immediately above Taylor Creek at RM 29.5. The primary reason for segmenting the river at this location is the large volume of ground water inflow originating from Masonry Pool and significant surface water inflow entering in the vicinity of Taylor Creek.

- *Cedar Falls Study Area*: This reach extends from RM 29.5 upstream to the Cedar Falls powerhouse tailrace at RM 33.7. The primary reason for this segment break is the immediate influence of powerhouse operations on river flow and the absence of significant inflows in this reach.

- *Canyon Study Area*: This reach extends from RM 33.7 upstream approximately 0.5 miles to RM 34.2, which is the location of the first natural barrier impassable to anadromous fish. The primary differences between the Canyon Reach and the Cedar Falls reach are channel morphology and the effect of Seattle City Light's bypass diversion on stream flows through the Canyon Reach.

TARGET SPECIES

Target species and life stages were selected in consultation with the Instream Flow Committee and are shown in Table 3.3-1 (Cascades Environmental Services 1991).

Table 3.3-1. Target species and life stages per study area.

Species	Life Stage	Study Area			
		Lower Cedar	Upper Cedar	Cedar Falls	Canyon
Winter and Summer Run Steelhead	Spawning	x	x	x	x
	Effective Spawning	x	x	x	
	Juvenile	x	x	x	x
	Adult Holding	x	x	x	x
Sockeye	Spawning	x	x	x	
	Effective Spawning	x			
	Cumulative Spawning	x			
Fall and Spring Chinook	Spawning	x	x	x	x
	Juvenile	x	x	x	x
	Passage	x			
Coho	Spawning	x	x	x	
	Juvenile	x	x	x	

OVERVIEW OF STUDY METHODS

The overall purpose of the study was to evaluate the instream flow and associated habitat requirements of salmon and steelhead in the Cedar River. Studies and analyses conducted between 1986 and 1996 include instream flow using the IFIM, sockeye and steelhead habitat preferences, effective spawning analyses, cumulative spawning analyses for sockeye and steelhead, redd scour studies, flow accretion studies (inflows to the mainstem), and sockeye and chinook run timing analyses and ramping rate (rate of flow decrease) analyses. Every aspect and detail of these study methods and associated analyses required the review and consent of the Committee before and during execution.

The study program was intensive. Over 15,000 individual measurements of river depth, velocity, substrate composition, cover, channel morphology, fish habitat preferences, and other variables were collected during 50 days of field work for crews of between two and five biologists. Methods for each of these studies are briefly described below.

IFIM Studies

The IFIM is the prescribed method of state and federal agencies for determining instream flow requirements in Washington State. The IFIM developed by the USFWS (Bovee 1982, 1986) is based on the premise that stream-dwelling fishes prefer a certain range of depths, velocities, substrates, and cover types, depending on the species and life stage, and that the availability of these preferred habitat conditions varies with stream flow. With input of stream flow, substrate, and cover type measurements, the IFIM uses a set of computer programs developed by the USFWS to quantify habitat availability over a range of flows. It is important to recognize that the result of the IFIM is not an absolute value but a range of values to be used as a tool for determining the appropriate stream flow or set of stream flows.

Application of the Cedar River IFIM followed a collaborative and thorough study scoping and design process in accordance with WDF IFIM study guidelines. Important fish habitat was mapped and incorporated into the study design using habitat maps and analysis of color aerial photographs, a low level aerial videotape, and topographic maps. With maps and photos in hand, Cascades Environmental Services met individually with WDF regional biologists who had first-hand knowledge of Cedar River fish life history, habitat use, and distribution. Final study designs were approved by the Committee.

Physical habitat parameters were measured using standard techniques according to Trihey and Wegner (1981), Bovee (1982), WDFW (1989), and the Cedar River IFIM scoping reports. Cedar River IFIM measurements extended over 32 miles of the river from just upstream of the City of Renton to the anadromous barrier falls, 0.5 miles above the Cedar Falls Powerhouse. A total of 63 study transects were selected to represent the mix of fish habitat and stream channel types in four study areas.

Flow Accretion

Flow accretion is the gain in river discharge between two points as a result of surface or subsurface inflows from tributaries, seeps, or upwellings. Understanding and quantifying the pattern and magnitude of surface flow accretion (and loss) is an important component of the instream flow study. In order to integrate hydrology with habitat and to provide a useful tool for water and natural resource managers, it was necessary to mathematically combine habitat from all IFIM locations along the river. Also, in order to correctly quantify the amount of habitat relative to the optional Renton or Landsburg control points, it was necessary to determine the cumulative discharge at IFIM study locations and Renton relative to any given bypass (discharge) below the Landsburg Diversion Dam.

Inflow is the primary hydrologic factor needed to integrate habitat between the study locations. Final accretion methods and analyses included Cedar River Inflow III analysis (Sun 1986), USGS records, Cascades Environmental Services flow measurements, and basin area calculations. The Committee agreed to use the 1929-1988 period of record as the basis for accretion analyses.

Fish Passage

Shallow depths across a riffle or gravel bar can limit a fish's ability to swim upstream. This type of barrier is called a *low-flow blockage*. If the shallow depth condition occurs just prior to the spawning period, upstream spawning migration can be blocked. Low-flow blockage conditions in a stream are a function of channel morphology, depth of flow, and flow timing.

The occurrence of low-flow blockages in a stream increases as the discharge drops during low-flow conditions. Under these conditions there are usually one or two critical riffles that are most sensitive to reductions in discharge and first become limiting as flows drop. If sufficient flows are maintained over these critical sections of the river then passage is assumed possible in all sections of the affected river reach. The critical passage section on the Cedar River was found at the shallowest and widest riffle in the river, approximately 0.5 miles upstream of Rock Creek (note that this is the Rock Creek below Landsburg).

Low flow passage criteria for salmon and steelhead were developed by Thompson (1972). According to Thompson, the minimum depth criteria are used only to ensure that fish have physical freedom to move throughout the stream. The minimum depth criteria do not account for the effect of short-term high flows on inducement of migration. Because of its large size relative to other salmonids, chinook salmon was chosen as an indicator for successful passage of all species. According to Thompson, chinook passage is not impeded if a depth of 0.8 ft is met over 25 percent of the total stream width *or* over a continuous 10 percent of the total stream width. Using IFIM cross-section measurement methods and the hydraulic model, the selected cross section was analyzed to determine the effect of the different discharges on stream depth relative to the passage criteria of Thompson.

Habitat Suitability Studies

The basic components of riverine fish habitat are space, water quality, flow, and cover. IFIM habitat suitability studies are designed to determine the suitable range of the flow and cover habitat components preferred by each species and life stage being studied. Although the USFWS maintains a large database on the habitat suitability of many species and life stages of fish, fisheries biologists recognize that a species' preferences may vary somewhat from stream to stream. For this reason the Committee directed that habitat suitability studies be conducted on sockeye and steelhead in the Cedar River. Habitat suitability for coho and chinook were obtained from the WDF.

Habitat suitability curves for sockeye spawning, as well as steelhead spawning and rearing, were developed from site-specific observations, existing curves from other rivers, data analysis, interpretation, and negotiation. The forum through which suitability curves were developed was the Cedar River Instream Flow Preference Curve Subcommittee. Members of the subcommittee included individuals from the City, Cascades Environmental Services, WDF, WDOE, the Muckleshoot Indian Tribe, USFWS, and the ACOE. Curves developed were used in the IFIM.

Effective Spawning Analysis

The purpose of the effective spawning analysis is to determine how best to protect against suffocation or dehydration of incubating eggs that may result from controlled stream flow reductions during or following the spawning period. The effective spawning model uses the hydraulic output from the IFIM to predict the discharge at which spawning areas in the stream could become dewatered. The effective spawning habitat model used in this study was adapted from an FRI model developed for similar evaluations of Seattle City Light's Skagit River Hydroelectric Project. The model was modified by the Committee for use on the Cedar River for sockeye. Of particular concern to the Committee was selection of the appropriate criteria for the minimum water depth required over a redd that would prevent egg suffocation. Considering the lack of reliable scientific data on depth criteria and the danger of setting the criteria too low, the Committee recommended that a conservative depth criteria of 0.3 ft be used in the model.

Ramping Rates

Fry and juvenile salmonids and other fishes are vulnerable to sudden flow reductions in the Cedar River. Fish can be killed by becoming stranded on open gravel bars or by isolation in potholes or side channels that subsequently dry up. To prevent such occurrences, the WDF has established ramping rate guidelines that limit the rate of flow reduction. The ramping rate guidelines are most effective when they are coupled with site-specific information such as river channel morphology, hydraulics, and species presence, and water project operational constraints and flexibilities. The primary source of information for the Cedar River on the relationship between reductions in discharge and streambed exposure was output from the IFIM.

Cumulative Spawning Analysis

The purpose of the cumulative spawning analysis as envisioned by the Committee was to determine if sockeye spawning potential in the Cedar River below Landsburg Dam could be maximized through regulated incremental increases in discharge during the spawning period. This "stepped flow" approach would theoretically provide maximum spawning potential by progressively adding habitat from the middle of the channel toward the edge of the channel through the duration of the sockeye spawning period. The cumulative spawning model was developed in a collaborative process with the Committee. The primary data source for the cumulative spawning model is spawning habitat output from the IFIM.

Redd Scour Studies

Flood flows in the Cedar River have been determined to have an adverse impact on sockeye egg survival. Because of this potential impact, the Committee was concerned that a negotiated lower flow during the sockeye spawning period could increase egg mortality by concentrating spawners in the mid-channel zone where bed scour is presumably more likely to occur. Related to this concern was the Committee's desire to provide safe areas for spawning, presumably along the margins of the river, where bed scour would not occur or would be less severe.

Three different methods were investigated to understand and quantify the relationship between spawning flow, flood flow, and the potential for sockeye redd scour. The three methods are outlined below.

(1) A radiotelemetry method was developed by Cascades Environmental Services, in consultation with the Committee, in which small radio transmitters were buried in sockeye redds and then monitored for displacement during subsequent flood events. During the 1990 sockeye spawning period, 30 transmitters were buried in active sockeye redds at locations along the margins (presumed safe zone) of the channel and in the center (risk zone) of the channel at depths ranging from 0.25 to 0.75 ft. The transmitters were then monitored in real time with a multiple channel receiver for displacement during one minor and one major flood event of November 1990. The exact time of transmitter displacement was later cross-referenced to the USGS gage record at Renton to obtain river discharge at the moment the redd was scoured to the depth of the transmitter.

(2) A preliminary Incipient Motion Model was developed by Cascades Environmental Services and West Consultants, Inc., in consultation with the Committee, that used particle grain size data and output from the IFIM, results of the radio telemetry study, and bed movement equations to correlate site-specific bed movement to a specific flood discharge.

(3) An Edge Spawning Habitat Analysis method was also developed in consultation with the Committee. The basic purpose of the Edge Spawning Habitat Analysis was to examine the range of flows necessary to provide suitable sockeye spawning habitat in specified edge areas along the margins of the river. Output from the IFIM was the primary source of data for this method.

Three possible widths of safe zones were selected for the analysis: (1) the outer 10 percent of the wetted perimeter of each transect; (2) the outer 20 percent of the wetted perimeter of each transect; and (3) the outer 30 percent of the wetted perimeter of each transect. Percentages were equally split between the left and right banks. Wetted edges used to calculate the specific width of each safe zone for each transect were obtained from the IFIM model at flows of 400 and 600 cfs, as measured at the Renton gage. The IFIM data set was then modified to calculate WUA inside the safe zones only, excluding all habitat in the channel between the safe zones.

DATA ANALYSIS AND STUDY PRODUCT

IFIM Studies

IFIM data analysis required the use of a group of computer programs developed by the USFWS, called the Physical Habitat Simulation System. There are two main programs in this model: the hydraulic model, called IFG-4, and the habitat model, called HABTAT. IFIM data analysis involved close interaction with the Cedar River Instream Flow Committee. The Committee met on several occasions to review, discuss, and approve model calibration procedures.

The IFG-4 hydraulic simulation model predicts water depth and mean column velocity across the stream as a function of discharge. A log-log regression analysis was used to develop stage-discharge relationships at each transect and to predict velocity/discharge relationships at each habitat cell. Interpolation and extrapolation with the regression equations allowed modeling of flows between and outside the measured discharges. The resulting simulated hydraulic information was then input to the HABTAT program.

The HABTAT program integrates the simulated hydraulic information from IFG-4 with habitat suitability criteria and quantifies habitat availability over a range of flows for the specified target species and life stage. Habitat quantification is expressed as WUA, or square ft of habitat per 1,000 linear ft of stream.

The products of the IFIM and hydrologic studies were a series of tables and graphs representing the relationship between discharge (measured at either Landsburg or Renton) and total WUA (habitat) in the Lower Cedar Study Area (Cascades Environmental Services 1991). A similar series of tables and graphs was produced for study areas above Landsburg representing the relationship between habitat and accretion, flow regulation at Masonry Dam, and flow regulation at the Cedar Falls powerhouse.

An interactive computer model was developed and made available to the Committee that would allow the user to calculate the effects of various accretion and water management and demand scenarios on WUA for all species and life stages through all the Cedar River study areas. This model was used extensively by the City in evaluating instream flow proposals.

Flow Accretion

The product of the accretion study was a series of tables and graphs showing cumulative accretion on a weekly basis at each IFIM study location and the Renton USGS gage. These data were integrated into all flow-related analyses and models.

Fish Passage

Although the absolute minimum flow that would allow passage was not determined, studies indicated that upstream passage of adult chinook would not be impeded at flows of 94 cfs or more. The Committee decided that studies of less than 94 cfs would not be necessary as long as negotiated instream flows (at the passage transect) were equal to or greater than 94 cfs (Cascades Environmental Services 1991).

Habitat Suitability Studies

Habitat suitability criteria (preference curves) were developed from field observations using the methods described by Bovee (1986) and from negotiations with the Cedar River Instream Flow Preference Curve Subcommittee (Cascades Environmental Services 1991). A full report on preference curve development is presented in Appendix E of the Final Instream Flow Report (Cascades Environmental Services 1991).

Effective Spawning Analyses

Effective spawning analyses were conducted as agreed upon by the Committee. The product is a series of matrices and figures that specify the post-spawning flow required to protect incubating sockeye and steelhead eggs from dehydration.

Cumulative Spawning Analysis

Cumulative spawning analyses were conducted as agreed upon by the Committee. The Committee's primary purpose for the cumulative spawning analyses was to determine the feasibility of the incremental approach to flow regulation and sockeye spawning habitat maximization. Assuming that incremental flow regulation was determined to be feasible, the second purpose of the spawning analysis was to determine what flow steps would maximize sockeye spawning potential.

The analysis showed that, theoretically, incrementally increasing flow through the sockeye spawning period results in an increase in WUA over a constant flow held through the spawning period. Optional flow steps for maximizing WUA were presented in the Final Report.

Redd Scour Studies

An overview of redd scour analyses and products is provided below.

(1) The Redd Scour Subcommittee found results of the Radio Telemetry Study inconclusive for the purposes of quantitatively defining risk zones and safe zones. However, the results did indicate trends and phenomena that may be useful in understanding bed scour and its potential impact on sockeye redds in the Cedar River. These indications are that: (a) scour of sockeye redds may be initiated at higher flows than previously suspected; (b) the results of the transmitter study strongly support the premise that short-term high river flows can significantly reduce egg-to-fry survival; and (c) safe and risk zones are not clearly delineated in terms of channel margin and mid-channel zones. A number of mid-channel telemetered redds incurred minimal scour at even the highest flood flows.

For a number of technical reasons the Incipient Motion method was discontinued by the Committee in December of 1994. At that time the Committee decided to further develop the Edge Habitat Analysis Method.

(2) The Edge Habitat Analysis Method proved the most useful of the three redd scour study methods for allocating sockeye spawning flows that would minimize redd scour resulting from flooding. The product of the edge habitat analysis is an interactive model that permits the user to calculate the effects of various accretion and water management and demand scenarios on availability of edge habitat in the Lower Cedar River Study Area.

3.3.3 Watershed Assessment

OVERVIEW

A Watershed Assessment was conducted during the summer of 1995 to develop and document a scientifically based understanding of the environmental processes and interactions occurring in the Cedar River Municipal Watershed that affect aquatic habitats. The Watershed Assessment followed procedures as described in the Washington State Watershed Analysis Manual, Version 2.0 (Washington Forest Practices Board 1993) or were slightly modified from the these procedures. Adjustments to procedures in the manual were employed to increase accuracy of the investigation. Procedures used in the Cedar River Watershed Assessment are detailed in Watershed Assessment Modules and Methodologies (Foster Wheeler Env. Corp. 1995b).

The State of Washington Watershed Analysis process is a structured resource specialist team approach for developing sound management decisions using the best available data. Watershed Analysis procedures were specifically designed to provide information for the development of management prescriptions (Appendix 16) that prevent, avoid, or minimize negative environmental impacts to natural resources and identify restoration opportunities. Watershed Assessment results were incorporated into a series of GIS maps depicting existing features, such as landslides, and areas of concern, such as high surface erosion potential areas (Appendix 15).

The Watershed Assessment was conducted by scientists employed by the City, Foster Wheeler Environmental Corporation, and Terrapin Environmental. Individual disciplines represented by the scientists included forest hydrology, forest engineering, geology, fisheries biology, and geomorphology. Modules within the Watershed Assessment included mass wasting (landslides), surface erosion, hydrology, riparian zones, stream channel, and fish habitat. The Watershed Assessment also incorporated information provided by regional experts in such forums as the Cedar River Watershed Bull Trout Workshop (Foster Wheeler Env. Corp. 1995d) and Watershed Conservation Biology Workshops (Foster Wheeler Env. Corp. 1995a) (Section 3.3.4).

At the time the Watershed Assessment was completed, the Water Supply/Public Works and Water Quality modules were not conducted, because the entire Cedar River Watershed is a drinking water supply basin and a specific Water Quality module did not formally exist. Even though no formal Water Quality module existed, the City has extensive water quality data for points throughout the watershed and these data were incorporated into the assessment.

The Watershed Assessment produced a number of reports documenting the assessments described above, such as the “Stream Channel and Fish Habitat Assessment” (Cupp and Metzler 1995) and the “Mass Wasting and Surface Erosion Assessment.” (Foster Wheeler Env. Corp. 1995c). A major product of the Watershed Assessment is a document entitled “Basin Condition Reports, Prescriptions, and Restoration Opportunities for the Cedar River Watershed Habitat Conservation Plan” (Seattle Water Department 1995), which is summarized below. Resulting prescriptions presented in this report are included in Appendix 16.

SUMMARY OF BASIN CONDITIONS REPORT

The Basin Condition Report provided a summary of basin conditions for eight physiographic regions and 24 hydrologic subbasins within these regions. These eight regions included the Lower Cedar River (Masonry Dam to Landsburg Dam) and Secondary Tributaries, Lower Glacio-fluvial Terrace, Taylor Creek, North Shore of Chester Morse Lake Reservoir, South Shore of Chester Morse Lake Reservoir, Rex River, Boulder Creek, and the Upper Cedar River. Each physiographic region summary provided the following information by hydrologic subbasin: (1) region overview discussing geology, geomorphology, history of resource use, and historic channel trends; (2) description of the fisheries resources; (3) discussion of potential and delivered hazards, including mass wasting and surface erosion, peak flows, and riparian function;

(4) identification of particularly important stream reaches and the response (low, medium, or high) of each channel segment to specific material (wood, sediment, etc.) or energy (water, temperature, etc.) inputs; and (5) restoration considerations.

The Watershed Assessment identified six principal elements that contribute to resource degradation within the Cedar River Watershed above Landsburg Diversion Dam. The six elements summarized below include past land management activities within inner gorges and on unstable hillslopes, hillslope surface erosion and runoff from road surfaces, past road construction methods, riparian zone degradation, and adverse impacts to the hydrologic regime.

Inner Gorges

Land management activities such as timber felling, ground-lead yarding, and road construction within inner gorges have destabilized over-steepened hillslopes producing a number of landslides that have delivered coarse and fine sediment directly to streams.

Hillslope Landslides

Similar to the situation with inner gorges, past land management activities such as timber harvest, yarding, and road construction using inappropriate methods on unstable or landslide-prone hillslopes have directly or indirectly led to a number of landslides that have delivered both coarse and fine sediment to downslope streams.

Hillslope Surface Erosion

Creation of impervious areas as a result of soil compaction and vegetation removal from inappropriate yarding methods and road construction has resulted in overland water flow that carries fine sediment to downslope streams. Additionally, removal of vegetation from highly erodible soils has resulted in fine sediment entering streams from soils exposed to water and wind.

Roads

Fish habitat has been degraded as a result of fine sediment entering streams from unprotected native soil road surfaces, drainage facilities, and road prism cut and fill slopes. Additionally, mass-wasting events from road embankment slopes have contributed coarse sediment to downslope channels.

Riparian Zones

The degradation of aquatic resources within the watershed has in part been a consequence of timber harvesting and road building within riparian areas and wetlands. Improper typing of streams (see Section 3.2.4) has also led to the degradation of riparian vegetation resulting in increased sediment, nutrient, and solar energy inputs.

Hydrology

Impacts to the aquatic resources as a result of timber harvesting and road construction over a large percentage of a subbasin can alter the hydrologic regime, potentially increasing the magnitude and changing the timing of peak flows. Peak flow increases can affect both channel stability and available fish habitat in heavily harvested watersheds.

POTENTIAL RESTORATION OPPORTUNITIES

Besides describing the current conditions of the aquatic resources, the Watershed Assessment also provided prescriptions to prevent, avoid, or minimize adverse impacts, and restoration opportunities for each physiographic region and specific recommendations for some of the 24 subbasins. Many of the restoration opportunities are not region- or subbasin-specific, but apply to the entire Cedar River Watershed. The seven primary restoration opportunities included in-channel placement of large woody debris, abandonment of roads, stabilization and revegetation of road cut and fill slopes, creation of off-channel rearing habitat in floodplains, restoration of riparian vegetation, replacement of structures (culverts and bridges) that block fish passage, and road resurfacing.

3.3.4 Summary of Workshops Sponsored by the City

Since 1991, the City has hosted a number of workshops on subjects related to the HCP or on specific parts of the HCP as it was being developed. These workshops provided an opportunity to solicit the perspectives of a variety of university, agency, and Tribal scientists in an interactive format with City staff. Many of the ideas developed in the workshops were incorporated into the HCP.

WATERSHED CONSERVATION BIOLOGY WORKSHOPS

Approaches to timber harvest in the context of landscape management were discussed at two conservation biology workshops the City held with scientists from the Pacific Northwest and agency biologists in 1995 (Appendix 14). The participants reviewed the following: work related to the HCP that the City had completed to date; the potential design and management of an ecological reserve; harvest of timber; species and habitats of concern; and proposed watershed restoration, mitigation, management guidelines, and monitoring.

The first workshop was held August 14, 1995. Along with City staff and consultants, participants included biologists from USFWS, NMFS, the U.S. Environmental Protection Agency, WDFW, and WDNR. A major point of discussion involved whether it was best to protect the entire northern spotted owl CHU (sections 3.2.2 and 3.5.2) in the reserve, or instead allow harvest of second-growth in the CHU and include additional mature, low-elevation, second-growth forest in the reserve to recruit more old-growth forest over time at lower elevation. A second major point of discussion involved the standards for tree retention when timber was harvested. The City proposed to generally follow the approach to retention recommended by Dr. Jerry Franklin in his New Forestry approach (Franklin 1989), but the City had not proposed specific standards at that time.

Following the first workshop, WDFW recommended specific tree retention standards in excess of state forest practices requirements (letter dated October 5, 1995). The recommended retention standards were incorporated into the City's mitigation strategy for the draft HCP.

The second workshop involved a number of prominent research scientists working in various aspects of conservation biology. In addition to City staff, consultants, and biologists from several federal and state agencies, participants included Dr. Gordon Orians, Dr. Jerry Franklin, and Dr. James Karr of the University of Washington; Dr. Dennis Paulson of the University of Puget Sound; Dr. Jan Henderson and Dr. Andrew Carey of the USFS; and Dr. Klaus Richter of King County. Participants agreed that the management of matrix lands (lands *not* in an ecological reserve) would ultimately determine the overall landscape connectivity.

The scientists at the workshop did not agree on any single overall approach to forest management, but four themes emerged:

(1) The importance of a core forest reserve system, particularly to protect aquatic habitats, with no timber harvest for commercial purposes;

(2) The importance of retaining biological legacies at harvest to carry over key processes that contribute to structural and biological complexity in the regenerating stands;

(3) The value of allowing harvested stands to mature and develop characteristics of mature forest habitat in the commercial harvest zone; and

(4) The importance of restoring degraded habitats, particularly the natural function of the riparian/stream complex.

Dr. Henderson, a plant ecologist, pointed out that having patches of mature forest distributed over the watershed would be the best strategy to create favorable conditions for such organisms as lichens, fungi, and mosses. There was a consensus that there should be no limit on harvest unit size, because such limits would produce more fragmentation. There was also consensus that tree retention standards should be applied on a landscape level, rather than a stand or harvest unit level, because site conditions would vary and strongly dictate the best retention strategy. For example, heavy retention would be unsuccessful in areas of high winds with blowdown potential.

Most of the scientists at the workshop, as well as the state agency biologists and environmental groups, have uniformly suggested that more of the mature, low-elevation second growth in the lower watershed should be included in the City’s ecological reserve. Based on the workshop discussion, input from the environmental groups, and meetings with WDFW and USFWS staff, a large block of additional low-elevation forest was added to the proposed Ecological Reserve in the draft HCP.

The scientists and agency biologists at the workshop also recommended that the harvest program incorporate long rotations, and Dr. Franklin recommended a higher average standard for retention of green trees at harvest, equal to about 20 percent of the stand volume. These two recommendations were also incorporated into the City’s mitigation strategy for the draft HCP.

OLD-GROWTH FOREST RESTORATION WORKSHOP

On October 2-3, 1991, the City hosted a workshop on old-growth forest restoration. The purpose of the 2-day workshop was to discuss whether silviculture could or should be used to accelerate development of old-growth conditions in older, previously harvested stands, and to develop approaches to restoration. Participants spent one day in the field visiting several stands in Cedar River Municipal Watershed, and discussing potential treatments to restore old-growth conditions. The second day was spent in a workshop setting at the University of Washington, during which objectives, silvicultural treatments, and issues were discussed.

In addition to City technical staff, participants included in the workshop were Dr. Keith Aubry, Dr. Andrew Carey, Dr. Dick Miller, and Dr. Lori Wunder of the USFS Pacific Northwest Research Station; Dr. Jerry Franklin, Dr. Gordon Orians, Dr. Chad Oliver, Dr. Dave Shaw, Dr. Steve West, Dr. Gordon Smith, and Mr. Dean Berg of the University of Washington; Dr. Gabe Tucker of Oregon State University; and Dr. Carol Perry of Corvallis, Oregon.

The workshop group agreed that some older stands could be silviculturally manipulated in a manner that would increase the rate of development of old-growth conditions. However, the group also concluded that, given the experimental nature of the silvicultural treatments involved, older stands that were beginning to develop internal structure naturally should be left to develop without intervention.

The group discussed forest habitat needs of species and species groups, including:

- Salamanders, which as a group need logs, healthy soils, streams, and ponds;
- Spotted owls, which need large, moderately decayed snags, live trees with cavities as habitat for prey, large live trees with platforms or cavities for nesting, diversity of fungi and lichens, and roosting and foraging perches in the mid-story;
- Open-nesting birds, which require a variety of types of nesting sites and foraging substrates;
- Winter seed-eating birds, which require seed crops from different tree species;
- Birds and mammals that use tree cavities;
- Bats, which need large trees with exfoliated bark for roost sites, as well as caves, rocks, and crevices; and
- Invertebrates, many of which need coarse woody debris and decadent canopies.

The group identified a number of desired features a forest manager might attempt to develop through manipulation of harvested stands to foster development of old-growth characteristics:

- A wide range of tree sizes, with large trees important;
- Both healthy and defective trees;
- A large accumulation of biomass;
- Large logs, ranging in diameter, length, and level of decay, with large logs important;

- Snags, varying in size and decay class, with large snags important;
- Forest floor conditions that support fungi and invertebrates, and soil structure typically present in older, naturally regenerated stands;
- A variety of vascular plants, epiphytes, and fungi;
- Spatial heterogeneity in forest structure and species composition; and
- Cold, clear streams, with low sediment levels and high levels of coarse woody debris.

Several silvicultural techniques were discussed that could produce the desired features of stands:

- Thinning to: (1) create variable spacing among trees, a diversity of tree diameters, and several canopy layers; (2) create forest openings to recruit desired plant species, and stimulate growth of large trees and understory shrubs and trees; (3) release intermediate-sized trees and advanced regeneration (small hemlocks); and (4) favor desired species or damaged trees, fostering structural and species diversity.
- Using equipment and other means to create desired tree conditions in the following ways: (1) create snags by topping, damaging, or burning trees; (2) create logs by felling trees; and (3) create cavities using chainsaws and fungi.
- Stimulating development of plant diversity by planting forbs, shrubs, and trees, spraying lichen fragments in the canopy, and damaging trees to create defects.
- Avoiding fertilization, because of possible impacts to soil systems.
- Leaving existing features that generate diversity, such as root rot centers.
- Enhancing hardwood development, recruiting species such as big leaf maple (*Acer macrophyllum*) to diversify stand structure and development of mycorrhizae.
- Uprooting trees to create logs, root masses, and holes.
- Using prescribed fire, only after a careful risk assessment, to control fuel loads.

The group identified some risks of thinning that would have to be addressed or controlled, including soil compaction, introduction of disease or insect infestations (by damage to live trees), reduction of natural tree mortality, creation of too much uniformity, and impact to shrubs and snags from heavy equipment. The group designed specific treatments for one stand, based on a field visit, inventory data, and growth modeling, and designed future experiments for restoration.

BULL TROUT WORKSHOP

On November 18, 1994, the City held a 1-day workshop at Cedar Falls on bull trout in the municipal watershed (Foster Wheeler Env. Corp. 1995d), in part because bull trout are present in the reservoir and because the species was under review for potential listing under the Endangered Species Act. The goals of the workshop were to identify relevant new or unpublished information about bull trout ecology; assess potential effects of reservoir operations and land management activities on bull trout; review and discuss the City's proposed mitigation plans; and generate ideas for ways to identify, protect, restore, and monitor important habitats.

In addition to City staff and consultants, participants included biologists from USFWS, NMFS, the Muckleshoot Indian Tribe, WDFW, University of Washington, and King County, as well as other experts on bull trout from the Pacific Northwest. These experts included Scott Craig and Fred Goetz, biologists who did master's degree research on bull trout; Dr. Karen Pratt, an independent consultant from Idaho; Dr. Dudley Reiser and Dr. Ed Connor of R2 Resource Consultants, who had been studying bull trout in the watershed for several years; and Don Ratliff of Portland General Electric Company, who had done research on bull trout in reservoir systems.

Agency and Tribal biologists who were participating in instream flow studies and negotiations for the HCP were also present for the workshop to foster a better discussion of reservoir operations that could affect bull trout and how those operations and their effects might be altered by water releases to maintain downstream river flows for anadromous salmonids.

The workshop format consisted of presentations followed by open roundtable discussions. Presentations included the potential impacts of water supply and watershed management practices on bull trout, and potential mitigation elements and benefits for bull trout. Information covered included the historic pattern of timber harvest, historic and current migration barriers in the mainstem Cedar River, and the biological significance of the Cedar and Rex river deltas.

The elements chosen to develop the protective stream buffer system of the HCP were explained. Preliminary results of the fisheries study by R2 Resource Consultants (in preparation) were presented, which summarized most of what is known about bull trout in the municipal watershed. Overviews were given of the factors affecting reservoir operations, the role of the temporary pumping plants for emergency supply, and instream flows in the lower Cedar River.

The potential impacts of water supply and watershed management practices on bull trout were presented and discussed. One issue discussed was that of timing and magnitude of reservoir levels with respect to the bull trout's annual life cycle. Bull trout are known to spawn during the fall in the lower reaches of the two major tributaries to the reservoir, the Rex and Cedar rivers (Section 3.5.6). Rising reservoir levels in the spring can cause inundation of some bull trout redds, with a potential for mortality of eggs and alevins because of sedimentation and reduced oxygen supply (Section 4.5.6).

Falling reservoir levels during the summer and fall, prior to the late fall rains, may restrict access by adult bull trout to tributary spawning areas, and fish passage between Masonry Pool and Chester Morse Lake is restricted at lower levels (Section 4.5.6). Other potential impacts that were discussed included: the possible effects of using temporary pumps to lower the reservoir below its gravity feed outlet; the possible effects of lowering Masonry Pool for maintenance at Masonry Dam; the significance of entrainment of bull trout into the hydroelectric plant intakes at Masonry Dam; the cumulative impacts on bull trout from past timber harvest; and the impact of poaching on the bull trout population.

Potential mitigation elements were discussed that addressed the effects of reservoir fluctuations; the cumulative damage to streams from prior timber harvest and road building; and proposed research and monitoring directed at protecting and restoring the bull trout and its environment in the municipal watershed. Participants felt that the most likely limiting stage in the life history of watershed bull trout is the period of juvenile rearing in streams. They thought that the City's proposed stream and riparian conservation strategy, with its emphasis on large buffer strips and protection and restoration of stream habitats for fish, was a key mitigation element.

There was a general acceptance by the group regarding the plans and direction the City was taking for the protection of the bull trout, but the group also recognized some importance uncertainties. Participants made the following recommendations to the City:

- Determine the significance of the potential problem of access to spawning tributaries during low water years;
- Design and carry out a study to determine the significance of the problem of bull trout redd inundation by the reservoir in the lower parts of the Rex and Cedar rivers;
- Obtain more complete information on bull trout distribution and specific spawning habitats in the watershed, using radio-tagging to survey smaller tributaries for bull trout spawning; and
- Attempt to quantify the number of fish entrained into the hydroelectric project through a comparative literature survey (Section 3.5.6).

The first three recommendations were incorporated into the HCP monitoring and research program (Section 4.5.4), and the literature survey was completed after the workshop (Appendix 19).

ANADROMOUS FISH MITIGATION WORKSHOP

The City conducted a 1-day workshop on December 18, 1995, to evaluate anadromous fish population restoration measures that were then under consideration for the HCP. These measures addressed sockeye, coho, and chinook salmon and steelhead trout in the context of mitigation for the fish passage barrier created by the Landsburg Diversion Dam.

In addition to City staff and consultants, workshop participants included biologists from NMFS, USFWS, the Muckleshoot Indian Tribe, WDFW, King County, and ACOE; a representative of the Puget Sound Anglers; and Dr. Tom Sibley and Dr. Chris Foote, fisheries scientists from the University of Washington. Representatives of several environmental groups were invited but did not attend. A report covering the workshop proceedings, including a list of attendees and materials distributed at the meeting, was prepared and submitted to the City (Montgomery Watson 1997).

The group discussed the status of sockeye, coho, and chinook salmon and steelhead trout in the Lake Washington Basin, as well as possible causes for recent population declines and the general lack of understanding of these causes. Issues that were discussed included:

- The need for continued studies to identify and fill key information gaps to support the development of effective restoration measures;
- The need to assess the feasibility of providing fish passage facilities at Landsburg and evaluate potential risks to drinking water quality and public health;
- The potential role of a supplementation facility (hatchery or spawning channel) in population support and restoration; and
- The need for careful monitoring of selected restoration measures, including the impact on drinking water from fish passage above the raw water intake, and potential impacts of artificially produced sockeye fry on wild salmonids.

Potential mitigation elements were discussed that included interim and long-term measures. Long-term measures could provide passage above Landsburg for steelhead, chinook, and coho; habitat protection and rehabilitation above Landsburg; artificial production facilities for sockeye as an alternative to passage above Landsburg; and habitat restoration below Landsburg. Interim measures would be implemented prior to passage of anadromous fish above Landsburg Dam and construction of sockeye production facilities. For chinook, coho, and steelhead, such measures could include emergency supplementation and/or critical studies needed to provide information for development of effective and biologically sound long-term restoration measures that could contribute to reversing the decline of the fish runs. For sockeye, such measures could include continued funding contributions to the Lake Washington ecological studies and continued operation of the interim hatchery at Landsburg.

Following the workshop, consultants to the City completed a risk assessment regarding the potential impacts of fish passage above the raw water intake on drinking water quality and safety (Section 3.3.5; Appendix 5). The purpose of the evaluation was to determine if passage of small numbers of salmonids (steelhead trout, coho, and chinook salmon) above the Landsburg diversion could be consistent with drinking water regulations and other drinking water constraints and objectives.

An open discussion was held on various issues related to restoration plans. Topics of discussion included: cost-effectiveness of different measures; the kinds of monitoring needed to determine the success of mitigation and detect problems; the nature of an appropriate balance between artificial production and habitat enhancement; and implementation timelines.

3.3.5 Water Quality Risk Assessment for Landsburg Diversion Dam Blockage

Public water systems are required to comply with the provisions of the federal Safe Drinking Water Act (SDWA) and its associated regulations, as developed and implemented by the United States Environmental Protection Agency (EPA) and the

Washington State Department of Health (WDOH). The SDWA was originally enacted by Congress in 1974, and was reauthorized and amended in 1986 and 1996.

The purpose of these regulations is to ensure that drinking water delivered to customers is of high quality, and is protective of public health. The regulations look at source water quality and protection, primary treatment reliability and efficiency, and distribution system water quality protection and maintenance. Each of the elements mentioned above are considered to be part of the multiple barrier approach to water quality enhancement. They build upon one another. Maintenance of the highest possible quality of source water is the first barrier of water quality protection used by Seattle Public Utilities. The high quality source water has enabled Seattle to maintain a high quality of drinking water without complex treatment systems.

Activities associated with the implementation of this HCP, especially fish passage facilities, have the potential to change the chemical, physical, and microbiological nature of the source water. The primary concern has been the potential for increased nutrient loading as anadromous fish are allowed passage above Landsburg Diversion Dam. Included in the Appendices to this document is a report prepared by CH2M Hill (Appendix 5) that specifically evaluates the potential water quality impacts of allowing anadromous fish above Landsburg Dam.

This risk assessment indicated that passage of chinook, coho, and steelhead above the raw water intake would be unlikely to pose risks to drinking water quality, largely because of the relatively low numbers of these species expected to spawn above the Landsburg Diversion Dam. However, the CH2M Hill report also indicated that there was some uncertainty with changes in particular variables, particularly pathogens, and recommended that monitoring be done prior to and after passage is effected. This monitoring recommendation has been incorporated into the overall research and monitoring program (Section 4.5.3).

In contrast to the small number of chinook, coho, and steelhead that could spawn above Landsburg – perhaps 5,000 fish – the escapement goal for sockeye in this habitat is 262,000 adults. The biomass of sockeye carcasses after spawning would be about 30 times as great as the biomass of the other species combined. Thus, the report concluded that passing sockeye above the raw water intake would pose an unacceptable risk to water quality.

A concern associated with the implementation of the HCP relates to the potential degradation of water quality during the construction of facilities in or near the raw water intake at Landsburg. Both the scheduling of construction and construction procedures are being developed to address this risk (Section 4.3.2), and water quality protection plans will be developed and implemented for each phase of work.

3.3.6 Cedar River Watershed Aquatic System Monitoring Plan

In 1994, the City of Seattle was awarded a Centennial Clean Water Fund Grant from WDOE to develop and implement an Aquatic System Monitoring Plan for the Cedar River Municipal Watershed. The main purpose of this program has been to collect information on the chemical, physical, and biological components of the freshwater streams of the watershed. A Technical Advisory Committee (TAC) was assembled to assist the City in designing the program. Participants on this committee included a variety of Seattle Water Department employees from different disciplines, representatives from the USFWS and NMFS, and Dr. James Karr from the University of Washington, who is widely recognized for his development of methodologies for assessing the biological integrity of aquatic systems (e.g., see Karr 1991). The TAC was provided with consultant support for additional expertise in the fields of statistics, fisheries, and hydrology.

Over a period of approximately 6 months, the TAC developed a 2-year sampling program that involved a combination of water quality sampling, hydrologic monitoring and aquatic insect sampling for the development of a *Benthic Index of Biological Integrity* (BIBI) for the watershed. Field sampling activities began in the fall of 1995 and extended through the fall of 1997. Data for this program are currently being analyzed by the USGS as part of an interagency agreement with the City of Seattle. A final project report for the program is expected by early 1999.

The primary goal of the program as adopted by the TAC has been to collect, analyze, and synthesize information that can be used to determine the condition of the aquatic system of the Cedar River Watershed for evaluating alternative management strategies and ensuring a reliable safe supply of high quality drinking water. In support of this goal, the monitoring program was designed with three main components: (1) the collection of hydrologic information; (2) the collection of water quality data; and (3) the development of a BIBI for the watershed. Outlines of these three main components are presented below.

HYDROLOGIC MONITORING COMPONENT

Objectives established for the hydrologic monitoring component include:

(1) Determining flow contributions and peak flows from subbasins;

(2) Evaluating the condition of the state of recovery of critical stream reaches;

(3) Collecting quantitative information that can be used to detect trends and construct predictive models;

(4) Determining land management impacts to the hydrology of subbasins; and

(5) Coordinating data collection with hydrologic needs of other branches of Seattle Public Utilities (for example, use of water management modeling tools such as yield (CUE) and forecast (SEAFM) models).

Data that has been collected for the hydrologic monitoring component includes:

(1) Stream flow measurements via:

- installation of continuous flow recorders at 17 locations;
- installation of staff gages at 29 locations; and
- installation of crest gages at 19 locations.

(2) Channel stability measurements at 10 sites, including:

- cross-sectional profiles;
- longitudinal profiles;
- channel width/width-depth ratios;
- Wolman pebble counts (Wolman 1954);
- stream channel stability evaluation (Pfankuch 1978); and
- Riffle Armor Stability Index (Kappesser 1992).

(3) Culvert surveys on all Type I-IV streams, and many of the Type V and untyped streams.

WATER QUALITY MONITORING COMPONENT

The objectives established for the water quality monitoring component include determining:

(1) Current condition of water quality throughout the Cedar River Watershed;

(2) Seasonal differences in water quality among sampling sites;

(3) A sampling design scheme that over time could be used to determine long-term trends;

(4) Whether or not a correlation between turbidity and flow and total suspended solids exist in the mainstem of the Cedar River and selected subbasins;

(5) What loading of nutrients and disinfection byproduct precursors that the Cedar River contributes to Lake Youngs; and

(6) If violations of State Water Quality Standards for Surface Waters and the Surface Water Treatment Rule are occurring in the watershed.

Data that has been collected for the water quality component includes:

(1) Turbidity, total suspended solids, and particle counts, and total organic carbon samples using a stratified hydrograph approach for collection of data at 11 stations in the watershed. Flow and temperature are also continuously monitored at these sites.

(2) Samples for nutrients, turbidity, total organic carbon, total suspended solids, and other parameters at four locations in the lower watershed under runoff and low-flow events. Runoff events included the first full bank-channel-width storm event of the season, one additional storm event, and the first full-bank channel snow melt runoff event in the spring over the 2-year sampling period.

BIOLOGICAL MONITORING COMPONENT

The objectives established for the biological monitoring component, which included the Benthic Index of Biological Integrity (macro-invertebrate sampling), include:

(1) Evaluating the condition and state of recovery of critical stream reaches, including segments susceptible to disturbance and streams with a unique or significant resource value;

(2) Detecting impacts to the aquatic system from land management activities, including road construction, use, maintenance, and abandonment, timber harvesting, and watershed rehabilitation efforts; and

(3) Establishing sampling sites that can be used as points of reference for evaluating the cumulative impacts from water supply operations and land management activities in the Cedar River Watershed.

Data that have been collected in support of this component include:

(1) Three benthic macro-invertebrate samples each were collected from one riffle at 46 different locations throughout the watershed for each year of sampling. Sampling station locations were selected based on a statistical stratification that includes: elevation (above and below 3,000 ft); stream order (1-3 and 4-6) (Strahler 1957); and the degree of human influence characterized by road density, percent of acres harvested within the last 40 years, and the number of stream crossings and miles of road within 100 meters of a stream for all of the land area draining to each sampling site. Additional benthic macro-invertebrate samples were also collected from pools at 10 sites.

(2) Other field data, including measurements of conventional water quality parameters and stream characteristics, were recorded at each site where aquatic insect samples were collected.

The final report providing an analysis of the data collected for the Aquatic System Monitoring is expected to be available by early 1999. If this analysis determines that a viable BIBI index has been developed for the watershed, then the macro-invertebrate sampling techniques should prove useful in prioritizing proposed stream restoration projects and evaluating the effectiveness of these projects over time. If the BIBI approach proves useful, it will be part of the long-term monitoring program for the HCP (Section 4.5)

3.3.7 Resource Inventory, Database Development, and Timber Harvest Modeling

INVENTORY AND DATABASE DEVELOPMENT

In 1991, the City initiated a comprehensive multi-resource inventory project to replace its outdated 1974 timber inventory. Utilizing satellite imagery and a modified satellite imagery vegetation classification developed by Pacific Meridian Resources for the USFS, the municipal watershed and a 1-mile buffer surrounding the watershed were stratified into thousands of distinct forested and non-forested habitat units, or polygons.

The forested polygons were then assigned classification labels based on physical attributes that included primary and secondary tree species, tree size, and tree stocking levels (density). To verify the accuracy of the satellite classification system, field inspections were conducted, and when necessary, changes were made to the classifications. Further refinement of the stratification was achieved by phototyping hundreds of additional non-forested polygons as small as 1/10 acre.

In addition to the satellite and aerial photo classification, the City conducted a systematic, multi-resource cruise to supplement the existing satellite data with ancillary data relative to wildlife habitat and commercial timber potential. Approximately 28 percent (23,000 acres) of the forested area of the watershed was field sampled at a stand level using a cruise intensity of one sample plot per 5 acres. Handheld data recorders were used to collect attributes such as tree species, diameter, and height, tree taper, defect, crown ratio, and age. Snags, stumps, and down logs were classified by decay class, and understory vegetation was recorded by species and percent cover. Sampled polygons were then extrapolated to unsampled polygons that had been assigned similar vegetation classes from the satellite classification. By integrating this stand-based inventory with the geographic information system (GIS), the City is now able to perform complex, spatial analysis.

Once the inventory and classification process was finalized, the watershed was then divided into 27 individual subbasins. This division process allows analysis on a much smaller scale, thereby allowing timber harvest simulations and habitat analysis on a subbasin level. For example, rain-on-snow harvest constraints can be modeled and outputs regulated accordingly to minimize any cumulative impacts on streams from harvesting within a subbasin.

Presently the watershed contains 4,117 polygons (90,546 acres total), of which 2,808 polygons (85,412 acres total) are forested and have a minimum size of 2 acres. Non-forested polygons are mapped to a minimum size of 1/10 acre. For each polygon there may be up to 140 different descriptive attributes. In order to store and analyze such a large amount of data, the City selected the Forest Projection System (FPS), a forest inventory software program developed and provided by Forest Biometrics, a consulting firm from Oregon.

FPS is a forest planning software program that links to external forest inventory databases for the purpose of long-range planning and analysis. FPS contains a set of utilities that process and extrapolate sample plot data, project future yields, and simulate various timber harvest regimes. FPS’s embedded growth model utilizes over 40 years of ongoing growth and yield research in the Pacific Northwest. In 1997, comprehensive calibrations were made to the western Washington yield tables (Western Washington Growth and Yield Calibration, Arney 1997), which significantly improved the growth model’s ability to account for natural tree mortality and inherent stand variability as a result of natural regeneration. Other growth models do not simulate this natural variability or a stand’s *clumpiness*, which in FPS is estimated using a stand’s clumpiness index.

The FPS harvest scheduler simulates various timber harvest regimes for up to 10 periods of variable length into the future. This is accomplished through the use of a search algorithm to schedule stands for harvest by user-defined periods. Harvest levels can be set to optimize yields or they can be regulated by various constraints such as rotation age, maximum number of acres, or rain-on-snow zone limitations. Polygons not available for harvest are passed to FPS from the GIS and coded so that they are not included in the schedule. Volume and economic reports provide the means to predict cash flow on a sustained-yield basis.

FPS's report functions allow for compiling individual stand data at any projected period in time, thereby providing a means to characterize and qualify future conditions. When linked to GIS, these FPS projections can be mapped and further analyzed. However spatially explicit mapping is only possible if each expected harvest unit is hand digitized, which the City did not do for the analysis of alternatives. Mapping by subbasin and stand is possible, but mapping of harvest units that are smaller than their parent stands cannot now be done.

Tree growth projections and harvest simulations for the HCP and various alternatives were carefully designed to ensure that each alternative's individual constraints and silvicultural regimes were met (see Revised NEPA EA/SEPA EIS). Volume outputs were then optimized. When the projections were completed, polygons were then compiled and classified so that wildlife habitat analysis could be performed. Data characterizing the forest cover for each polygon were generated for years 1997, 2020, and 2050. From this, a habitat rating system was applied. Volume and revenue outputs were reported by decade to the year 2050 so that cash flows could be evaluated.