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Modeling the Bull Run River-Reservoir System

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Proposal

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by

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Introduction

The City of Portland, Water Bureau currently operates 2 Bull Run reservoirs, Reservoir #2 and Reservoir #1 as a water supply source in the Bull Run watershed shown in Figure 1 and Figure 2. The Water Bureau wants to operate their water supply system in order to meet both water supply objectives and fish habitat objectives downstream of the Bull Run reservoirs in Bull Run River. In addition, a third Bull Run reservoir has been proposed as an additional water supply source. This reservoir also may be used to meet water supply and fish habitat objectives in Bull Run River.

This proposal addresses performing the following tasks to evaluate these objectives:

- Gather data to construct a computer simulation model of the Bull Run system including Bull Run River, Bull Run Reservoirs #1 through #3 and the river basin without reservoirs
- Ensure that the model accurately represents the system physics, chemistry and biology
- Use the model to evaluate how to meet water supply and fish habitat objectives by implementation of management scenarios

The proposal is divided into the following elements:

- Background Studies
- Modeling Approach
- Detailed scope-of-work and task list
- Project Schedule
- Project Deliverables
- References

Background Studies

The Bull Run system has been studied extensively by hydrologists and scientists. Some of these prior studies include:

- Temperature modeling in the Bull Run River below Reservoir #2 by R2 Resource Consultants, Inc. using the SNTEMP model (R2 Resource Consultants, 1997). The bathymetry data for Bull Run River and the shading data are important pieces of information for further model development described in this proposal.
- Evaluation of turbidity dynamics in the Bull Run Watershed by the USGS (LaHusen, 1994). This study evaluated cause-effect relationships between increases in turbidity and flows and geology in the basin. A relationship between suspended solids and turbidity was developed.
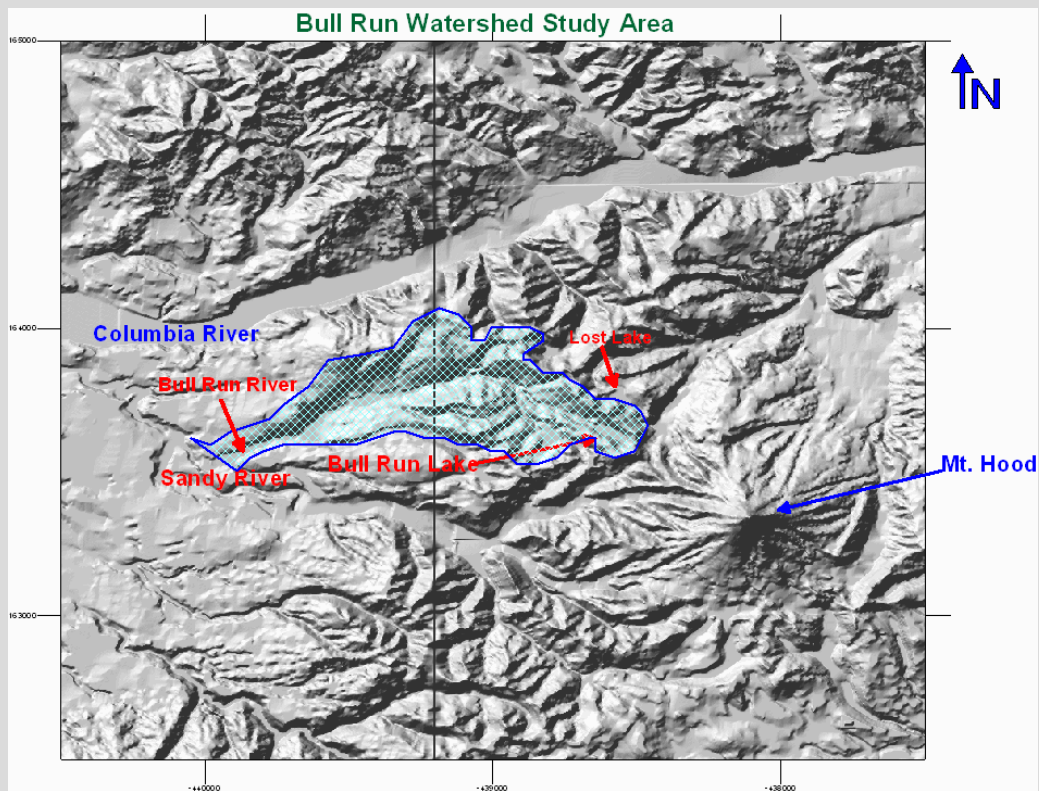

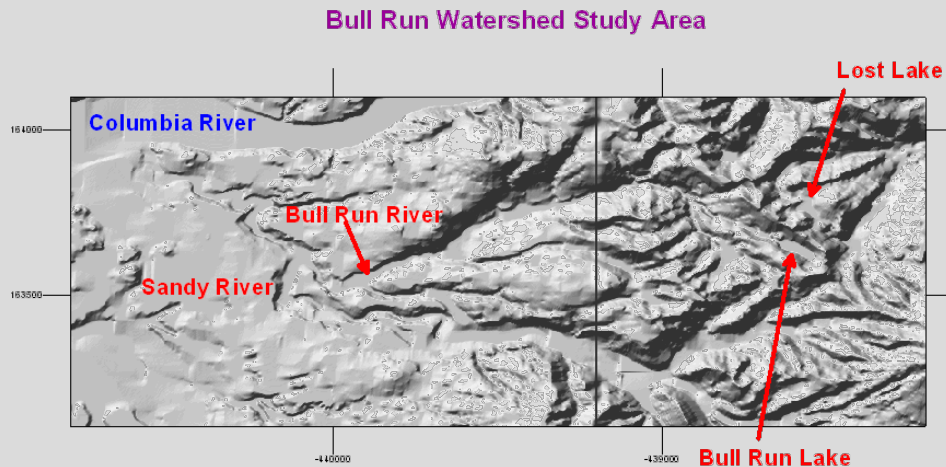**Figure 1.** Bull Run watershed in the Portland basin.

Figure 2. Bull Run study area.

- Analysis of water quality variations between 1978-1983 for the Bull Run River above the Reservoirs by the USGS (Rinella, 1987). This study also had statistical correlations of streamflow with basin area and precipitation, but these correlations were annual averages, rather than daily. This study should provide useful data on inflow water quality to the reservoirs and Bull Run Lake.
- A study of the hydrology of flows into the proposed Bull Run Reservoir #3 by Montgomery-Watson (1994). This study developed a correlation of flow rates at a USGS gaged location to one further up the Bull Run River that would be the inflow into Reservoir #3. A simple water balance model was used.
- A thorough review of water quality in the Bull Run Reservoirs by Environmental Chemistry, Inc. (1994). A simple well-mixed box model of the acid-base chemistry of the system was used for the reservoirs. Statistical correlations were performed for turbidity as a result of reservoir stage and precipitation volume.
- Sediment sizing on the deltas to the reservoirs and on the reservoir banks by Chester Environmental (1994).
- Evaluation of evidence of algal diatoms in the sediments (Sweet, 1992). There did not appear to be evidence of any green or bluegreen algae.
- A study on the hydrology of Bull Run Lake by the USGS containing useful information on inflows and outflows from the Lake (Snyder and Brownell, 1996)
- PSU studies of sediment deposition in the Bull Run watershed (Petersen, Hamilton, and Burns, 1995). This study performed sediment size distributions and sediment accumulation rates in Reservoir #1.

These studies will provide valuable information for estimating boundary conditions for the development of the Bull Run system model. These boundary conditions include estimating runoff into the reservoirs, sediment (turbidity), and water quality.

Modeling Approach

In order to have a model that is a reliable predictor of temperature and suspended solids (turbidity) in the reservoir system, a dynamic, spatially explicit hydrodynamic and water quality model is necessary.

Other models have been developed in past studies, and these include:

- Well-mixed box model for acid-base chemistry

Even though Environmental Chemistry (1994) recommended using a water quality and hydrodynamic model of the watershed, they did not have the resources allocated to pursue that task. The model used for their work was a well-mixed box, acid-base chemistry model.

- Well-mixed box model for volume conservation (Montgomery-Watson, 1994)
- SNTEMP model (R2 Resources, 1997) for the Bull Run River

The SNTEMP model was originally developed in 1984 and was based on predicting daily average stream temperatures using daily average meteorological data, stream morphology, and information on bank shading. The model uses Manning's equation for steady-state flow and also predicts daily maximum temperatures using a statistical regression model. This model is not able to predict instantaneous water temperatures and

is unable to model dynamic stream flow.

For this project, the CE-QUAL-W2 River Basin Model Version 3 is proposed as the most appropriate for modeling the Bull Run system since it contains the following elements:

- Two-dimensional, dynamic hydrodynamics and water quality capable of replicating the density stratified environment of the reservoirs and the sloping river channel sections as well
- Suspended sediment (and from correlation, turbidity) transport and deposition using multiple sediment sizes
- River-reservoir linkage is transparent for the Model User; there is no need to use one model for the river sections and another for the reservoir
- The model can be used to simulate ambient riverine conditions without the reservoirs in-place
- At a future time, Bull Run Lake can be connected to the system model as a waterbody even though it may not be directly connected to the Bull Run River; algorithms can easily be developed for flow from the Lake to the Bull Run River based on groundwater flow dynamics and inserted into the system model

This model has been under development for many years and is a public-domain code maintained by the Corps of Engineers, Waterways Experiments Station (WES), located in Vicksburg, Mississippi. The current version, Version 2 (Cole and Buchak, 1995), has been superceded by Version 3 developed by WES and Wells (1997). Version 3 has undergone rigorous testing (Wells, 1998) and has been successfully applied to the Lower Snake River system (Wells and Berger, 1998). This version has the ability to model the following parameters: dissolved and particulate non-living organic matter (both refractory and labile components), ammonia, nitrate, dissolved PO_4, 3 algal types, TDS, inorganic suspended solids, tracer, pH, total inorganic carbon, alkalinity, the carbonate species, and bacteria.

Conceptually, the model elements, shown in Figure 3, are

- Bull Run River below Reservoir #2
- Reservoir #2
- Reservoir #1
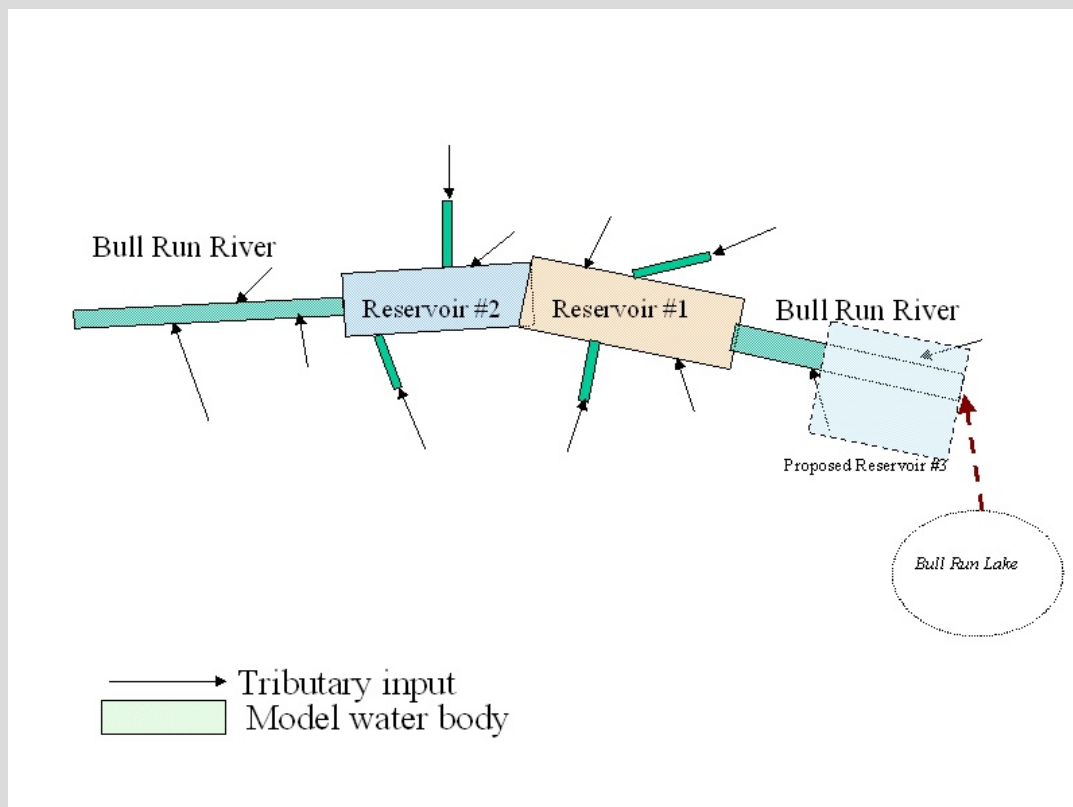- Bull Run River above Reservoir #1
- Reservoir #3

Figure 3. Conceptual layout of the Bull Run system.
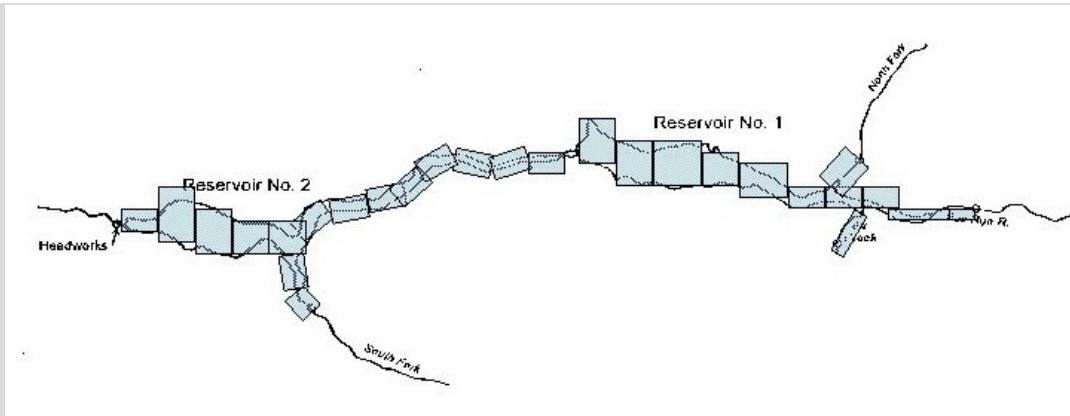
Figure 4. Preliminary conceptual layout of model segements for Bull Run Reservoir #2 and Reservoir #1.

Other tributary or branches may be added to the main system elements. Each of these elements will be broken into model branches (sets of segments) and segments (composed of vertical layers), as shown conceptually in Figures 4 and 5 for the Reservoirs and Bull Run River. A profile of the system model is shown in Figure 6. Computer animations for water temperature and turbidity will be developed based on this type of profile. A typical river or reservoir cross-section is broken down into several model layers as shown in Figure 7.
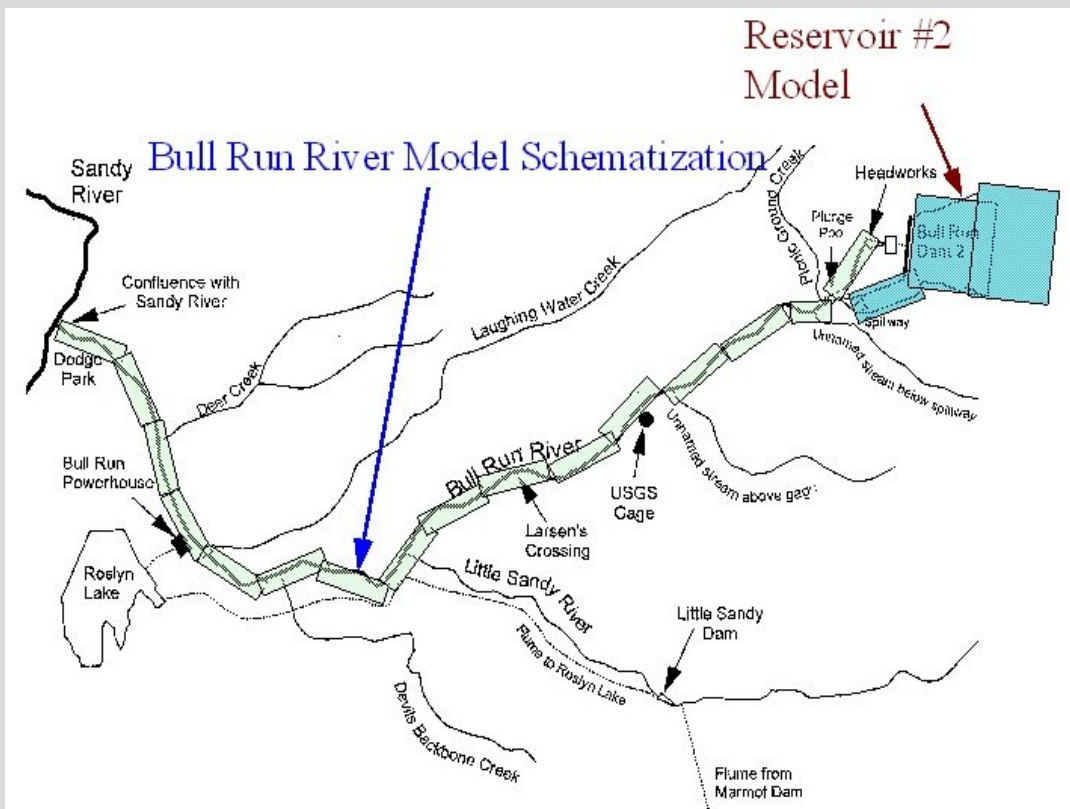
Figure 5. Preliminary conceptual layout of model segments for Bull Run River and part of Bull Run Reservoir #2.

Figure 6. Profile of Bull Run system model with Reservoir 3.
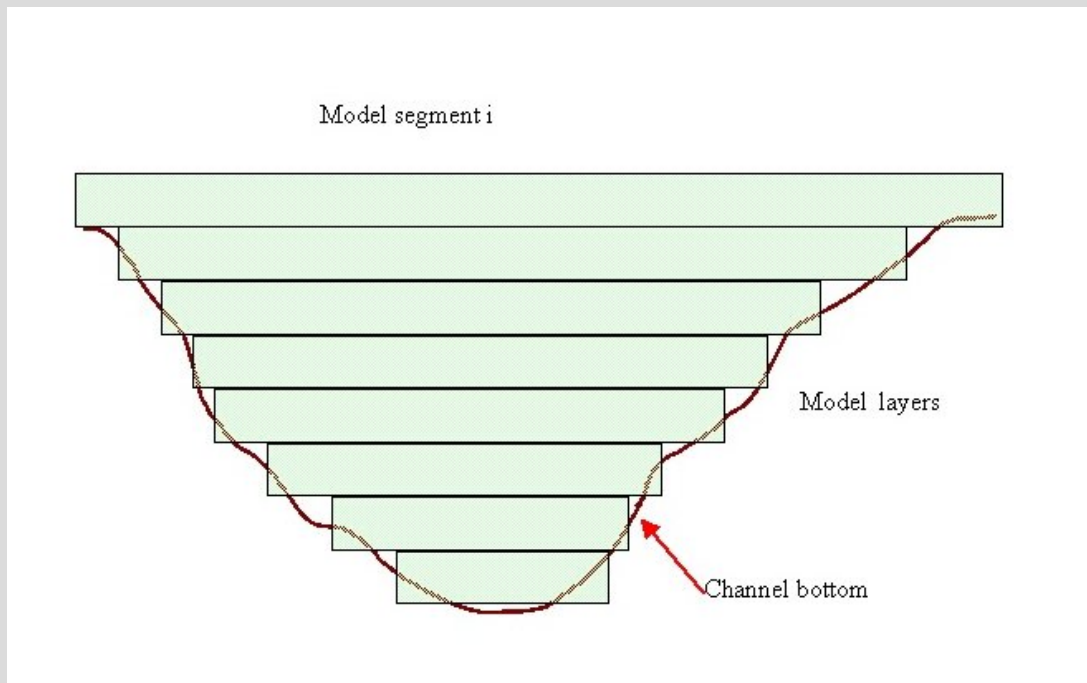
Figure 7. Channel layer schematization.

The model will be set up for calibration of turbidity, temperature, and dissolved oxygen data in the reservoirs and in the streams under existing conditions. Also, the model will be set-up to evaluate pre-impoundment conditions for temperature. The model will also be used to forecast the impacts of management scenarios on temperature and water quality conditions in the reservoirs.

Advantages of the Use of CE-QUAL-W2 over Prior Models Developed for the Bull Run System

Prior model studies of the reservoirs by Environmental Chemistry (1994) and Montogmery-Watson (1994) did not account for the complex circulation and stratification in the reservoir systems. These prior models assumed a well-mixed box for each reservoir. The CE-QUAL-W2

model was developed for narrow, deep, long reservoir systems that exhibit density stratified and density induced currents. The model also has selective withdrawal algorithms for the water withdrawals.

Other one-dimensional reservoir models, such as the HEC WQRRS (Water Quality River-Reservoir Simulation) model and the Corps's CE-QUAL-R1, are also not adequate to compute 2-D circulation within reservoir systems. These models conceptualize the reservoir as well mixed in each horizontal slab, i.e., over the length and the width of the system. By making this assumption, the vertical and longitudinal circulation patterns within a reservoir cannot be resolved.

A prior and on-going river modeling study using SNTEMP has been performed for the Bull Run River. The river modeling being performed using SNTEMP is different from that proposed using CE-QUAL-W2. Some of these differences and similarities are shown in Table 1.

Table 1. Comparison of SNTEMP and CE-QUAL-W2 models for riverine sections.

Model	Hydraulics	Meteorological data and temperature modeling	Shading
SNTEMP	Steady-state; most 1-D river models require a friction factor that varies with stream flow or stage	Model requires daily-average meteorological data (even though travel time from Reservoir #2 to the Sandy River can be less than a day) and computes daily-average temperatures; maximum temperatures are computed using a statistical correlation	Realistic topographic and vegetative shading algorithm
CE-QUAL-W2	Unsteady, multi-layer model with segment-by-segment variation of friction factors; ability to model system using one-friction factor for the entire range of flows	Model computes instantaneous solar radiation and will use 3-hourly updates for air temperature, dew-point temperature, wind speed/direction and cloud cover, model computes in-stream instantaneous temperatures	Realistic topographic and vegetative shading algorithm

The ability to model instantaneous temperatures as proposed using the CE-QUAL-W2 model is also critical to being able to evaluate model sensitivities and errors. Using the daily-averaged approach for the Bull Run River, as in the SNTEMP application, masks model errors and does not allow the modeler to understand model errors and weaknesses. In a river of such short travel time (a day or less), the Bull Run River below Reservoir #2 requires a model capable of predicting instantaneous temperatures.

Other 1-D river models could also be applied to the Bull Run River, such as Corps' CE-QUAl-RIV1 and the EPA's DYNHYD/WASP models. The CE-QUAL-W2 model though allows for deep pools in the river sections and allows for true 2-D river open channel flow. The advantages of CE-QUAL-W2 Version 3 to other river models were illustrated in Wells (1998). One primary advantage of CE-QUAL-W2 was that the friction factor did not need to be varied as the river stage increased.

Overall, the CE-QUAL-W2 model not only has a solid theoretical basis for modeling the Bull Run system, it also has state-of-the-art numerical schemes that minimize numerical stability and accuracy issues evident in older models. The new version 3 of CE-QUAL-W2 uses the Quickest-Ultimate Scheme for translating or advecting sharp fronts.

Scope-of-Work

In order to accomplish the objectives noted in the Introduction, the following list of tasks and sub-tasks will be necessary to be accomplished:

1. Background Data Analysis
    1. Data Acquisition from Water Bureau: Historical and current data for the Bull Run system will be obtained and organized at PSU into an ACCESS database for ease of retrieval and storage. Data necessary from the Water Bureau include:

    - Bathymetry data for Bull Run River (using data from the SNTEMP model), Reservoir #1, Reservoir #2, and the proposed Reservoir #3, as well as topographic information for drainage basins surrounding the Bull Run watershed.
    - Meteorological data from the Bull Run watershed and from the PDX airport
    - Temperature and water quality data from Bull Run streams and reservoirs. This includes water quality and temperature profiles

from the reservoirs, water quality and temperature data from Bull Run River and from Bull Run Lake.
- Suspended solids and turbidity data from the reservoirs and inflow streams. Particle size distributions, specific gravity, and correlations between turbidity and suspended solids from prior studies will also be used.
- Flow rate data. This includes flow rates passed through each reservoir and in-stream measurements of flow. Hydrological analyses performed on drainage basins from earlier studies will also be used to estimate streamflow.
- Water surface elevation data from Bull Run Reservoirs #1 and #2, as well as from Bull Run Lake

1. Analysis of Background Data
   0. Bathymetry data. These data will be imported into a 3-D terrain-mapping program in order to generate the bathymetry of the model and to compare with current estimates of theVolume-Area-Elevation for each reservoir. These data will also be used with the temperature profile data to estimate, prior to modeling, the volume of cold water available to be used for meeting fish habitat objectives in Bull Run River.
   1. Meteorological data. If little data are available from the Bull Run system, an attempt will be made to correlate Bull Run meteorological data with NOAA Portland International Airport (PDX) data and/or use theoretically based corrections to air and dew-point temperature based on elevation differences between the Bull Run watershed and the PDX airport.
   2. In-stream temperature, water surface and water quality data. These data will be used for calibration of the Bull Run system model. Also, PSU will provide animations of in-stream data if there is a sufficiently high-resolution (in time and space) data set for evaluation.
   3. Flow rate data. These data will be used as boundary conditions for the model.
2. Generation of Boundary Conditions for flow, temperature and water quality for the Bull Run watershed. The Bull Run system receives inflows from rainfall, runoff, and snowmelt. In order to model the reservoir system, an accurate accounting of the flows and quality/temperature of those flows are necessary. There are several approaches to this problem. One approach is to model each drainage basin using the EPA models HSPF or SWMM and predict the temperature and quality from each basin. This approach is too time-consuming to be used during this initial study since it also would require additional field studies. Alternatively, the net inflow to each reservoir can be determined using the water surface elevation data, known outflows and reservoir bathymetry. Then the computed inflows would be disaggregated to each major inflow stream based on its drainage basin area. The filtered equilibrium temperature based on meteorological conditions would be computed to estimate inflow temperatures using techniques developed in Adams and Wells (1984). Other aspects of the water quality, including sediment and turbidity, are more difficult to estimate and would need to be based either entirely on data correlations or on theory with data for calibration and verification. Prior hydrological studies of the basin will also be used extensively. In general, measuring stations for flow and quality will be used as upstream boundary conditions for the system model. These include stations located at South Fork in Reservoir #2 and at North Fork in Reservoir #1. The Bull Run River gage above Reservoir #1 will be used for initial calibration of the reservoir models and will be initially used for the upstream boundary for Reservoir #1. But this boundary will change once the upper section of the Bull Run River is modeled. At that point the Bull Run River gage above Reservoir #1 will be used as a calibration location for the model.

1. System Model Set-Up. The CE-QUAL-W2 river basin model Version 3 will be used for the Bull Run system since it is uniquely able to model the entire system with a state-of-the-art hydrodynamic and water quality model. This model application will initially involve modeling temperature, suspended solids, water surface elevations, and vertical and horizontal velocities. The suspended solids will be broken down into several size fractions. Work performed by Petersen et al. (1995) analyzed 5 sand size fractions, 3 silt, and 3 clay fractions. Initial model work will also use these 11 size fractions for suspended solids. Turbidity will also be predicted based on data correlations with suspended solids. The model incorporates the effect of suspended solids on light penetration and density induced currents.
   1. System Model Schematization. Layout the model domain and grid for the river and reservoir/lake model branches. Evaluate grid resolution issues.
   2. Determine Model Calibration Time Period. Determine the model calibration period based on available data.
   3. Preparation of Model Input Files. Prepare model input files for inflows (flow rates, temperature, and water quality), outflows, meteorological conditions, and bathymetry
   4. Model Alterations. The existing model needs to be adapted to the specific needs of the Bull Run system. This includes adding the following algorithms to the CE-QUAL-W2 Version 3 code: shading algorithm that was originally developed for the Columbia Slough model, additional suspended solids particle size fractions (the current code has one sediment size fraction). With the addition of Bull Run Lake to the system model, a groundwater flow algorithm may be necessary to link the Lake to the Bull Run River.
   5. Identification of Additional Field Sampling. More refined field data may be necessary to set up the model. These data will be identified based on a model sensitivity analysis.
2. Model Calibration/Verification. Compare model predictions of temperature, suspended solids (turbidity), dissolved oxygen, and water surface elevation to field data. Other parameters also may be compared. Adjustment of model parameters so that model predictions agree reasonably with field data. A formal sensitivity analysis will be performed and documented. Development of computer graphics/animations to explain Bull Run system dynamics.

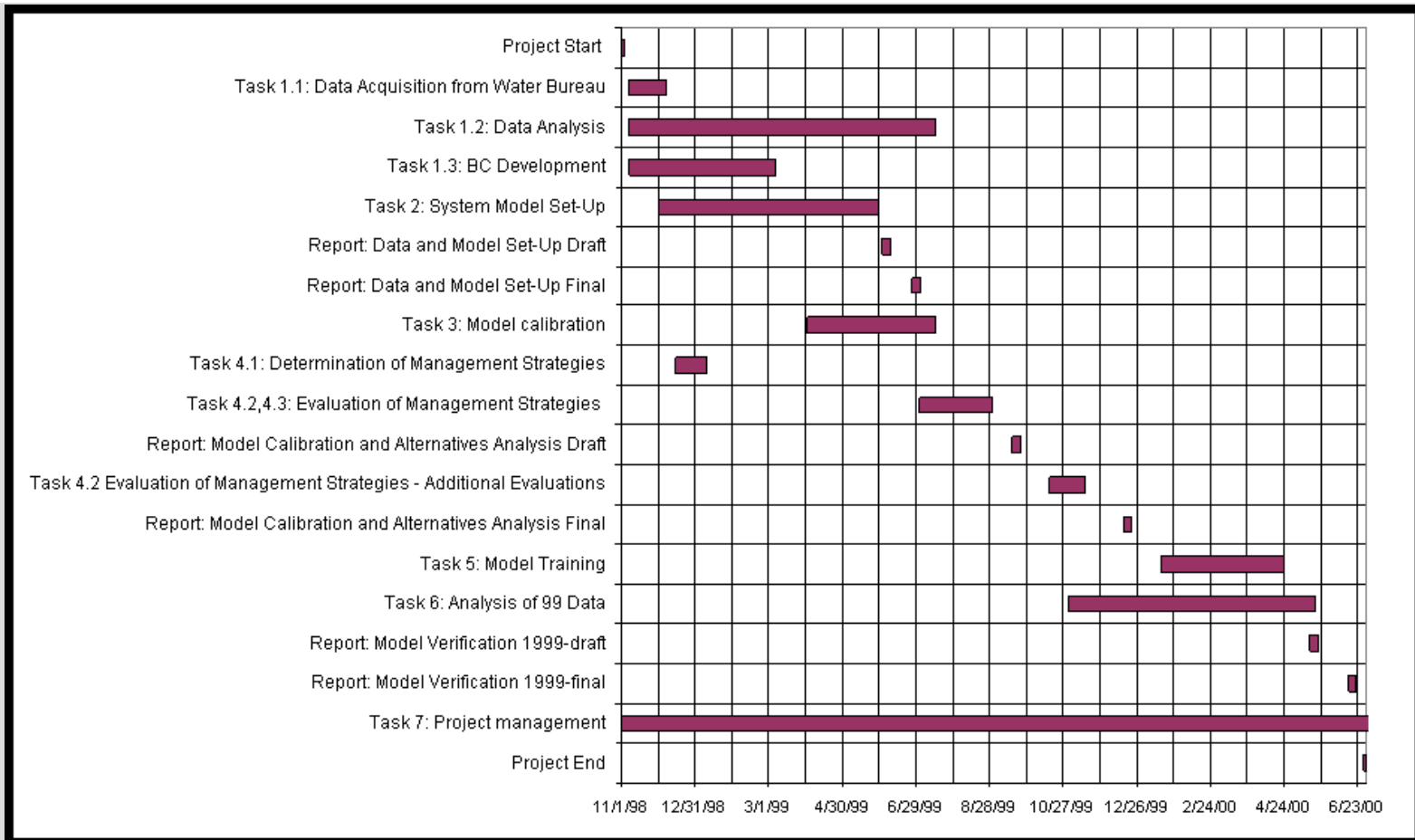3. Evaluation of Management Strategies for Water Supply and Fish Habitat Objectives
   1. Determination of Management Scenarios. In conjunction with the Water Bureau and its consultants, determine a list of management scenarios to evaluate using the model.

2. Implementation of Management Scenarios with the System Model. The model will be used to evaluate each management scenario and provide statistical, graphical and computer animation evaluations.
3. Development of the Bull Run River system without reservoirs. The Bull Run system will be modeled without Reservoir #1 and Reservoir #2. Simulations will be made evaluating the natural ambient temperature regime.
4. Model Training for Water Bureau Staff. PSU will provide a succinct User's Manual for the model and provide training for staff at the Water Bureau on running the model and using the model to evaluate additional management scenarios.

5. Analysis of Summer 1999 Field Data. The summer of 1999 field data will be put into the ACCESS database developed earlier. The data will be visualized and evaluated. Also, the model will be used to verify field data for 1999. This will ensure reliability of the Bull Run system model.

6. Project Management. Attend meetings with the Water Bureau, its consultants, regulators, and citizen groups explaining the modeling process and the results, manage PSU staff, report/memo writing

7. Possible Additional Topics. These topics are not explicitly included in the scope-of-work since many of the issues related to this would need to be explored after many of the work tasks are completed.
    1. Sediment Transport Modeling. The above model will be able to transport suspended solids and deposit it, but it does not have a feedback with the geometry of the system to change the bathymetry nor to scour it during periods of high shear stress. In this case, a predictive sediment scour model would be developed based on field data of particle size distribution and other laboratory tests. PSU has the laboratory facilities to measure the physical properties of solids: a HIAC particle size analyzer, electronically controlled settling column for particle settling velocity determination, oven/muffle furnaces, analytical balances.
    2. Watershed Model Development. Use a hydrologic model, such as SWMM or HSPF, and tie it into the Bull Run system model for prediction of runoff. Develop a field study plan for data necessary to calibrate a watershed model.
    3. Graphical User Interface Development. Develop a GUI interface so that Water Bureau staff can easily use the model. This interface would use Visual Basic. The interface can be designed for use by someone trained, or for someone with little or no training, such as for the general public.
    4. An additional algorithm that may be necessary is the inclusion of a more complex sediment-heat flux algorithm. The current CE-QUAL-W2 model does not account for solar radiation being absorbed in the sediment and re-radiating or re-diffusing heat back into the water column. The importance of this issue will be determined by an evaluation of model sensitivities and calibration. This may especially be important in shallow stream sections exposed to sunlight.
    5. Operational Tool Development. Use the Bull Run System model to forecast operational strategy for the system based on meteorological data. Use the model in a forecasting mode to meet operational objectives.

Project Schedule

The project schedule is shown on the following page and assumes a project start of 11/1/98. PSU recognizes the importance of meeting the Water Bureau's deadline of 9/99 for making significant management decisions regarding Bull Run Reservoir #3 and flow and temperature releases in the Bull Run River. A draft report on the calibration and management issues is scheduled for the 9/99 time frame with the final report coming after public comments and after any additional management scenarios were run. Project end date was set as 6/30/00 in order to complete further work required by regulators, Bureau staff, or the public as a result of the publication of the draft report, to explore the summer 1999 data set in terms of model reliability, and to train Water Bureau staff in the use of the model.

Project Schedule

The Gantt chart shows the following tasks with a timeline from 11/1/98 to 6/23/00:

- Project Start
- Task 1.1: Data Acquisition from Water Bureau
- Task 1.2: Data Analysis
- Task 1.3: BC Development
- Task 2: System Model Set-Up
- Report: Data and Model Set-Up Draft
- Report: Data and Model Set-Up Final
- Task 3: Model calibration
- Task 4.1: Determination of Management Strategies
- Task 4.2,4.3: Evaluation of Management Strategies
- Report: Model Calibration and Alternatives Analysis Draft
- Task 4.2 Evaluation of Management Strategies - Additional Evaluations
- Report: Model Calibration and Alternatives Analysis Final
- Task 5: Model Training
- Task 6: Analysis of 99 Data
- Report: Model Verification 1999-draft
- Report: Model Verification 1999-final
- Task 7: Project management
- Project End

Project Deliverables

PSU plans to deliver the following items to the Water Bureau:

- A technical report on the background data analysis and model set-up
- A technical report on the model calibration and model alternatives analysis
- A technical report on the analysis of 1999 field data
- Technical memoranda as required
- CD containing the model code and project files
- CD containing model animations of calibration and alternatives analyses
- Train City of Portland Water Bureau staff on the use of the model and provide a User's Manual

In addition, the principal investigator will be available to make presentations or to act as a consultant for the Water Bureau during meetings with Bureau staff, its consultants, and the public.

Personnel

The project manager will be Dr. Scott A. Wells, Professor of Civil Engineering. Mr. Robert Annear and Mr. Chris Berger, both Ph.D. students in Civil Engineering, will be assisting in data acquisition, model set-up, model calibration, and management scenario development. Resumes of these individuals are attached to this proposal. Other graduate students in Civil Engineering may be used during the project period.

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