State of Maine
Department of Environmental Protection
Quality Assurance Project Plan for Model Simulations in the Total Maximum Daily Load (TMDL) Program

Prepared by
State of Maine
Department of Environmental Protection
State House #17
Augusta, Maine 04333-0017

Prepared for
U.S. Environmental Protection Agency
New England Office
1 Congress Street, Suite 1100
Boston, MA 02114

Approvals Signature (required prior to project start):

Signature	Print Name	Date
Maine DEP Project Manager	Dan Albert	Date: 7/9/08
Maine DEP Quality Assurance Manager	Malcolm Burson	Date: 7/9/09
Maine DEP Division Director	D. Courtemanch	Date: 7/9/09
U.S. EPA Project Manager/Officer	JENNIE E. BRIDGE	Date: 7/13/09
U.S. EPA QA Manager/Representative	John Smaldone	Date: 7/9/09

RFA #09141

Table of Contents

1.0 PROJECT MANAGEMENT

1.1 Title and Approval Page - See page 1.

1.2 Table of Contents - See page 2.

1.3 Distribution List – Maine DEP Modeling Quality Assurance Program Plan Distribution List.

QAPP Recipient/Title	Organization	Telephone Number
Malcolm Burson, QA Manager	Commissioner's Office, Maine DEP	207-287-7755
Andrew Fisk, Director	Bureau of Land & Water Quality, Maine DEP	207-287-7949
David Courtemanch, Director	Division of Environmental Assessment Bureau of Land & Water Quality, Maine DEP	207-287-7789
Barry Mower, Biologist III	Rivers Assessment Section, Maine DEP	207-287-7777
Rob Mohlar, Senior Environmental Engineer	Rivers Assessment Section, Maine DEP	207-287-4301
Donald Albert, Senior Environmental Engineer	River Assessment Section, Maine DEP	207-287-7767
Susanne Meidel	Division of Environmental Assessment Bureau of Land & Water Quality, Maine DEP	207-287-6710
Jennie Bridge EPA Project Officer	US EPA Region I	617-918-1685
John Smaldone	US EPA Region I	617-918-8312

1.4 Project Organization – See key individuals and organizational chart below. The purpose of this document is to present the QAPP for conducting modeling to support development of TMDLs. The QAPP provides general descriptions of the work to be performed to support TMDLs and the procedures that will be used to ensure that the modeling results are scientifically valid and defensible and that uncertainty has been reduced to a known and practical minimum.

A graded approach will be applied to projects in order to apply an appropriate QA level with the confidence needed in modeling results. The fundamental requirements that define the QA level include:

- The Intended Use of the Model – Higher standards are required for projects that involve potentially large consequences.

- The Scope and Magnitude of the Project – The more complex the project and model, the more detailed the QA effort that will be necessary.

Although there are no explicit categorizations or guidelines for applying the graded approach, a generalized methodology has been identified in QA/G-5M – Guidance for QAPPs for Modeling (EPA 2002). It allows QA activities to be adapted to meet the rigor needed for the project at hand. If a project addresses regulatory compliance or TMDL implementation, significant QA planning is necessary.

1.4.1 Key Individuals/Titles and Responsibilities

Quality Assurance Manager: Is responsible for oversight of the quality procedures and has independence from all units generating data and modeling. In addition, the Quality Assurance Officer oversees training and may issue stop work orders.

Director, Bureau of Land & Water Quality: Is responsible for management of the water quality assessment projects.

Director, Division of Environmental Assessment: Is responsible for direction of the water quality assessment projects and maintains the official approved QA Project Plan.

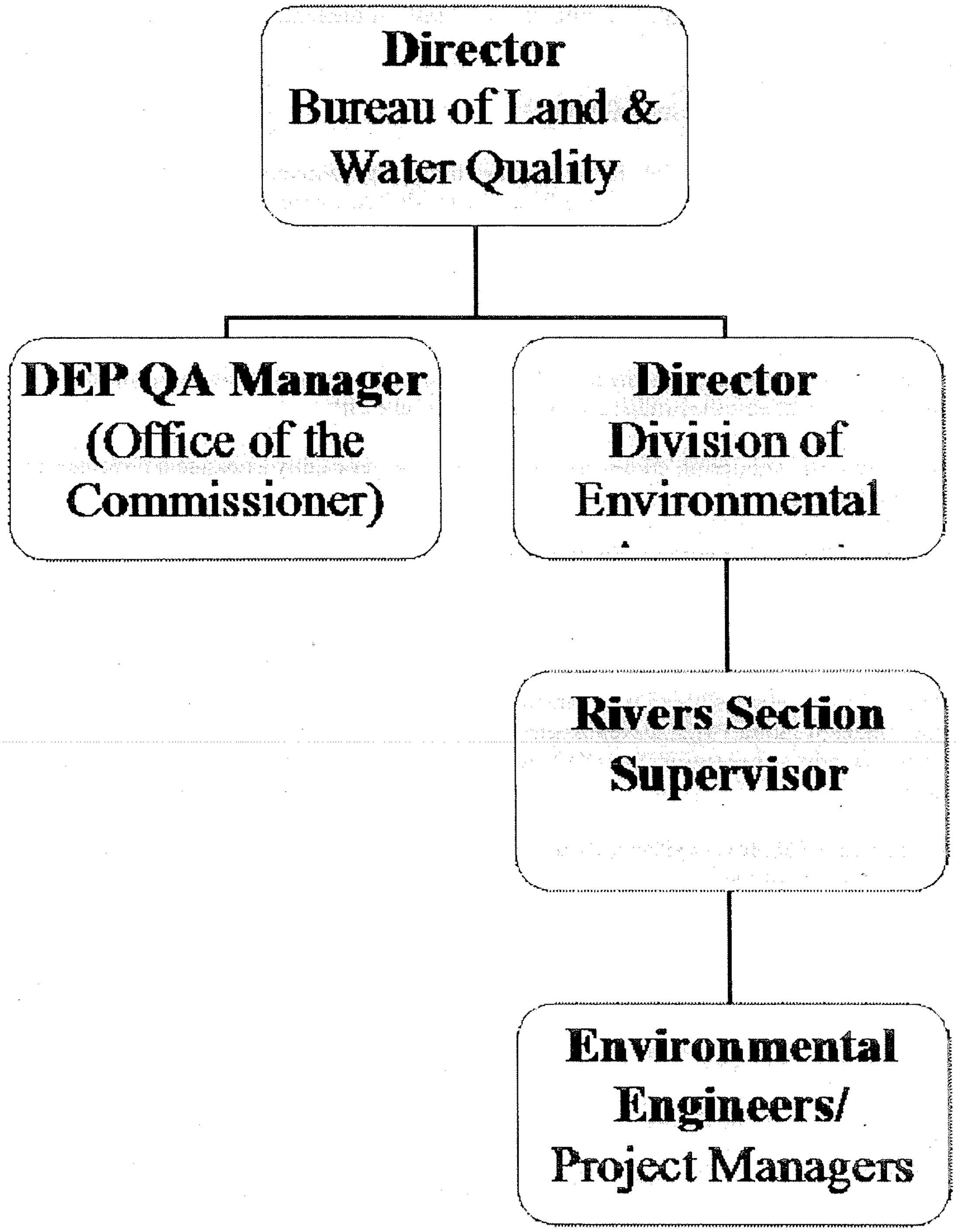
Section Manager, Rivers: Is responsible for supervising the rivers water quality assessment projects and is designated Section Manager.

Biologist I: Is responsible for entering and maintaining data

Project Manager(s): Are responsible for implementation of the quality plan and modeling rivers and streams and is a designated Project Manager.

EPA-NE Project Officer: Is responsible for receiving the modeling report from ME DEP and reviewing the report in the context of future TMDL development. The PO also approves QAPP and QAPP addenda, if any, and receives reports, as necessary. The PO provides assistance or seeks out others who may provide assistance.

EPA QA Representative: Approves QAPP and QAPP addenda, if any. Provides assistance or seeks out others who may provide assistance.


Director
Bureau of Land & Water Quality
DEP QA Manager
(Office of the Commissioner)
Director
Division of Environmental
Rivers Section Supervisor
Environmental Engineers/
Project Managers

1.5 Problem Definition/Background

This document represents a generic Quality Assurance Program Plan for the Division of Environmental Assessment, Bureau of Land & Water Quality. It covers quality assurance elements for model *applications* only. Modification of the QAPP will be required when projects will involve new model *development*. It may also be applicable to subcontractors under DEP supervision.

In Maine, an excess pollutant load can result in a violation of water quality standards. A TMDL analysis is prepared to estimate the total load that a water body can accept and attain water quality standards. Historically, development of TMDLs was first mandated by the Clean Water Act in 1972, and was applied primarily to point sources of water pollution. As a result of public pressure to further clean up water bodies, lake and stream TMDLs are now being prepared to include Non-Point Sources (NPS) of water pollution. Major land use activities contributing to the load in water bodies include residential-commercial developments, agriculture, roadways, and commercial forestry.

Statewide, there are approximately 988 miles of rivers and streams which do not meet water quality standards out of a total of 31,218 miles. TMDL reports identify regulatory criteria for water bodies and are based on available water quality data such as total phosphorus, chlorophyll-a, and dissolved oxygen. The process includes a public participation component to allow for public review. Model performance and model outcomes under this QAPP will address the available regulatory criteria.

The department's TMDL Rivers and Streams Project Leader is Barry Mower. His responsibilities are listed on page 5 and include notifying the QA Manager and EPA Project Officer when new models will be created, justifying the inability to use existing models and if modifications to the model code will be necessary.

Model Assessment and Selection

Model assessment and selection is usually completed at the initiation of modeling projects by the Maine DEP in order to identify a successful approach for modeling. As part of the review process, publicly available simulation models are evaluated in order to identify the most appropriate modeling tool for characterization of point and non-point sources. A number of standardized modeling packages are reviewed by the Maine DEP. They have the following advantages:

1. Comprehensive documentation is distributed including a users manual, conceptual representation of the model process, explanation of theory and numerical procedures, data needs, data input format, and description of model output.
2. Technical support is typically provided in the form of training, use-support, and continual development from federal or academic research organization like EPA, USDA, and USGS.
3. Standardized modeling software has a proven track record, providing validity and defensibility when faced with legal challenges.

4. They are readily available to the general public (non-proprietary).

Selection criteria include length of model development history, applicability at the needed scale, and ability to predict the impact of land management practices on water, sediment, and agricultural chemical yields. The degree of certainty needed in model outputs is defined on a project specific basis through model optimization techniques. Certainty end-points, when specified, are model performance goals as some amount of irreducible error is inherent in all modeling. Section 4.3.1 identifies a few assumptions for modeling. Project specific assumptions in the modeling process will be documented in the modeling journals and reports.

1.6 Project/Task Description and Schedule

Modeling will be conducted to support TMDL development. TMDLs are important tools for maintaining and protecting acceptable water quality. They are primarily designed to 'get a handle' on the magnitude of the pollution problem and to develop plans for implementing Best Management Practices (BMPs) to address the problem.

As a rule, some 303(d) listed TMDL water bodies in Maine are monitored annually during which water chemistry measures are also collected (e.g., specific conductance, total alkalinity, and color), along with Secchi disk transparency, total phosphorus, Chl-a and dissolved oxygen/temperature profiles. Annual Sampling and Analysis Plans (SAP) produced for TMDL sampling include the water bodies to be monitored, frequency and intensity. The sampling data are used to support modeling. Additional data sources are identified in Section 2.0 and any maps for modeling projects will be in the modeling reports.

Schedules for modeling work are project specific. In general, modeling work may take up to a year or more to complete. However, with many regulatory agencies involved, there may be additional technical evaluations requested that may require additional time that may impact the schedule. Regulatory agencies may also require more time for review of model results and to reach consensus at key decision points. More specific resource or time constraints cannot be foreseen at this time but, if significant, will be communicated from the Maine DEP Project Manager to the EPA Project Officer.

1.7 Quality Objectives and Criteria for Measurement Data and Models

Quality objectives and criteria for model inputs and outputs are qualitative and quantitative statements that (1) clarify study objectives, (2) define the appropriate type and acceptance criteria of existing data, (3) establish acceptable model input and parameterization (calibration) criteria, (4) outline model performance evaluation obligations, and (5) specify tolerable levels of potential decision errors. Each is discussed in the following sections.

Assessing whether the DQOs have been achieved for a modeling study is less straightforward than for a typical sampling and analysis program. The usual data quality indicators (e.g., completeness, representativeness, comparability) are difficult to apply and in many cases do not adequately characterize model output. The ultimate quality test for the model is whether the output sufficiently represents the natural system that is being simulated. To a large extent, this is determined by the expertise of the modelers and the amount of available data. Nonetheless, there are objective techniques that can be used to evaluate the quality of the model performance and output. The methods, and the proposed performance expectations, are discussed in Section 1.7.2 below. Evaluation criteria are also provided in Section 4.3.1.

1.7.1 Objectives and Project Decisions

The QAPP has been completed by Maine DEP to ensure that (1) modeling input data are valid and defensible, (2) model setup and parameterization (calibration) protocols are followed and documented, (3) model applications and output data are reviewed and evaluated in a consistent manner and 4) that models are able to predict hydrologic or water quality conditions over time in support of TMDL development.

If modeling indicates that water quality standards are attainable, then discharge permits may be modified (or other pollution prevention measures taken) to improve water quality. To this end, modelers will work with program managers to align model outputs with the types of decisions to be made.

1.7.2 New Data Measurement Performance Criteria/Existing Data Acceptance Criteria

The use of existing data of known quality will help ensure that the modeling effort yields accurate predictions with an acceptable level of model uncertainty. All model input or parameterization (calibration) data sources will have a QAPP in place prior to the use in the modeling effort. Data with unknown quality (i.e. collected without a documented QAPP or using unapproved SOPs) will be flagged and noted as either conditionally acceptable for limited use or not acceptable for use at all. See also Section 2.1 for additional procedures for excluding data.

<u>New and Existing Data</u>

As an example of quality control, duplicate water samples are obtained for one out of every 10th water bodies sampled. Duplicate results are expected to be within 10% of each other 75% of the time and 20% of each other 90% of the time. Laboratories are expected to provide their own internal approach to quality control for each parameter in the SOP. For example, duplicate samples are routinely submitted by Maine DEP for analysis so that the labs may perform splits as necessary to meet their quality objectives.

Blind splits may be provided for inter-lab comparisons at the beginning of the monitoring season and periodically through the season to achieve comparisons of 2% of the overall number of samples for a given parameter. Results from these splits are expected to be within 15% of each other 75% of the time and 25% of each other 90% of the time.

When quality objectives are not met, and best professional judgment indicates sampling error, procedures are reviewed to determine which steps are critical for establishing consistency. Further detail may be added or modifications made to the SOP. When quality objectives are not met, and best professional judgment indicates analytical error, the lab will be contacted and some resolution to the problem will be sought. If DQOs cannot be resolved, the data will be censored. Circumstances where best professional judgment might not indicate evidence of sampling error or analytical error include results obtained from extremely oligotrophic waters, where parameter levels are extremely low. Similarly, extremely productive waters may yield results for duplicate samples that are highly variable due to the patchy nature of algal cell distribution within the water column.

Data of known and documented quality are essential to the success of the modeling projects. All model input or parameterization (calibration) data sources will have a QAPP in place prior to the use in the modeling effort. These, in turn generate information for use in decision-making. Maine DEP has established Data Quality Objectives (DQOs) for modeling projects in order to specify the acceptance criteria for existing model input, and parameterization (calibration) or corroboration (validation) data. DQO's identify the (1) type and quality of data that will be appropriate for use in the modeling project, (2) spatial and temporal input data coverage requirements, (3) data quality and currency, and (4) technical soundness of the collection methodology. A list of related requirements is shown below.

- All input and parameterization (calibration) data for the model will be of a known and documented quality.
- Data will be collected from as many sources as available, and provide the maximum temporal and spatial coverage of the watershed drainage.
- The data will be comparable with respect to previous and future studies.
- Modeling data will be representative of the parameters being measured with respect to time, location, and the conditions from which the data are obtained.

DQOs for models specifically include:

- The ability to quantify future spatial and temporal distribution of sediment, toxic pollutants or nutrients in the watersheds.
- Flexibility to evaluate historical and relative contributions of various pollutant sources in the watersheds.
- Adequate resolution to identify the relative in-stream impacts of pollutant loading to the stream system from various urban and non-urban point and non-point sources.

DQO's are further refined in order to define performance criteria that limit the probability of making decision-based errors. They address the data validity and reliability of the modeling effort and each is briefly described below in the context of completeness, representativeness, and comparability. The traditional context of precision and accuracy is not included due to the fact that, in most cases, the data has already been collected and analyzed through acceptable analytical procedures.

Completeness is a measure of the amount of valid input data obtained during a process. The target completeness for models will be 100 percent – i.e., all available sources included. The actual completeness may vary depending on the intrinsic availability of monitoring data. Deficiencies in water quality, climatic, or stream flow data are outside of the control of the modeling effort and will be addressed as part of the data compilation and assessment effort. In order to provide surrogate data, the most current statistical or stochastic methods will be used to extend or fill in missing time-series data. The normal-ratio will be used to fill precipitation gaps. Discharges will be linearly interpolated or estimated using other fitting methods such as regression analysis. Maine DEP will address any data issues as they develop.

Representativeness is a measure of how closely the input or parameterization (calibration) data will reflect the physical characteristics of hydrology and water quality over time. Standardized monitoring plan design and the use of Standard Operating Procedures (SOPs) for discharge measurement, soils identification, land cover mapping, sample collection and handling, and acquisition of weather data are crucial to ensuring representative data quality. All model input or parameterization data sources will have a QAPP in place prior to the use in the modeling effort.

Comparability expresses the confidence with which one data set can be compared to another. Data comparability from external sources is very much tied to the individual project methodology and time at which it was collected. For the purpose of the modeling effort, comparability will be maintained by using consistent units, appropriate temporal scales, and reproducible methods. Unit conversions (metric may be the required default), datum transformations, and grid re-projections will likely be required to make data for the modeling comparable. Data that exists outside a reasonable temporal scale, has significantly changed or will potentially alter the modeling results are not comparable. DEP will make these determinations, as necessary. Comparability between other model indicators will be evaluated on a case-by-case basis.

Acceptance Criteria for Model Parameterization (calibration)

The acceptance criteria for model parameterization (calibration) define the procedures whereby the difference between the predicted and observed values of the model are within an acceptable range, or are optimized. Often parameterization is the only method to ensure that model predictions correlate with values observed in the field. Parameterization uses observed hydrometeorological data in a systematic search for parameters that yield an acceptable fit of computed results. This search is performed to find a reasonable best estimate that will yield the minimum value of an objective function, or variable that is critical in application. Parameterization has become increasingly important with the need for valid and defensible models for TMDL development. Acceptance criteria for the modeling projects are established by the Maine DEP prior to the initiation of the effort in order to provide a numerical ruler for determining whether the model is an appropriate tool for TMDL decision-making. As an example, the model parameterization criteria are based on the recommended error percentages for seasonal, annual, and storm-based water yields (Table 2-1). Generalized information related to model parameterization criteria, and corroboration considerations, include the following references: Thomann, 1982; James and Burges, 1982; Donigian, 1982; ASTM, 1984.

Table 2-1. Acceptable Model Parameterization (calibration) Hydrology Criteria

Errors (Simulated-Observed)	Recommended Criteria
Error in Total Volume	10%
Error in 50% Lowest Flows	10%
Error in 10% Highest Flows	15%
Seasonal Volume Error – Summer	30%
Seasonal Volume Error – Fall	30%
Seasonal Volume Error – Winter	30%
Seasonal Volume Error – Spring	30%
Error in Winter Storm Volumes	20%
Error in Summer Storm Volumes	50%

Graphical comparisons of model performance may also be used including time series plots of observed and simulated flows and state variables, and residual scatter plots (observed versus simulated values). Time series plots are generally evaluated visually for agreement, or lack thereof, between the simulated and observed values. When observed data are adequate, or uncertainty estimates are available, confidence intervals can then be calculated so they can be considered in the model performance evaluation.

A number of statistical tests are also available for watershed model evaluation and optimization. The Sum of the Squared Residuals and the Nash & Sutcliffe Coefficient of Efficiency are two that have been identified for the purpose of the modeling project. Each is described below.

Sum of Squared Residuals is a commonly used objective function for hydrologic model parameterization (calibration). It compares the difference between the modeled and observed ordinates, and uses the squared differences as the measure of fit. Thus a difference of 10 feet^3/second between the predicted and observed values is one hundred times worse than a difference of 1 feet^3/second. Squaring the differences also treats both overestimates and underestimates by the model as undesirable. The function implicitly is a measure of the comparison of the magnitudes of the peaks, volumes, and times of peak of the hydrographs and water quality constituents. The equation for calculation of the sum of least squares is shown below (Diskin and Simon, 1977).

Sum of Squared Residuals

$$Z = \sum_{i=1}^{i_n} [q_o(i) - q_s(i)]^2$$

Where:

Z = Sum of Least Squares
q_o = Simulated Discharge
q_s = Observed Discharge

Nash and Sutcliffe Efficiency is a goodness-of-fit test as a statistical method for evaluating the hydrologic variability between measured and predicted model values. The Nash and Sutcliffe Coefficient of Efficiency (COE) provides a normalized estimate of the relationship between the observed and predicted model values and is calculated as below (Nash and Sutcliffe 1970).

Nash & Sutcliffe Efficiency

$$COE = 1 - \frac{\sum_{i=1}^{i_x} [q_o(i) - q_s(i)]^2}{\sum_{i=1}^{i_x} [q_o(i) - \overline{q}_o(i)]^2}$$

Where:

COE	= Coefficient of Efficiency
q_s	= Simulated Discharge
q_o	= Observed Discharge

A COE value of one indicates a perfect fit between measured and predicted values for all events. COE values between zero and one suggest a positive relationship between observed and predicted values, thus allowing for the use of predicted values in lieu of observed data. A zero value indicates that the fit is as good as using the average value of all the measured data. See also Section 4.1 for additional parameterization considerations and stop criteria.

Model Corroboration (Validation)

Corroboration (validation) is defined as the comparison of modeled results with independently derived numerical observations from the simulated environment. Model corroboration is an extension of the parameterization (calibration) process. Its purpose is to assure that the calibrated model properly assesses the range of variables and conditions that are expected within the simulation. Although there are several approaches to validating a model, perhaps the most effective procedure is to use only a portion of the available record of observed values for parameterization. The rest is used for corroboration. Once final parameterization parameters are developed, simulation is performed for the remaining period of observed values and the goodness-of- fit between recorded and simulated values is reassessed. Wherever possible, this type of split-sample parameterization and corroboration procedure will be used for modeling projects.

The credibility of the model hinges on the deterministic ability to predict conditions over the entire range of observed data: in effect, validating the model. For flow and water quality simulations where continuous records are available, multiple corroboration techniques will be used. For example, comparisons of simulated and observed state variables will be performed for daily, monthly, and annual values. Statistical procedures mentioned in Section 4.2 will be used to assess the parameterization. These include error statistics, correlation and model fit efficiency coefficients, and goodness-of- fit tests. For sediment and water quality data, model performance will be based primarily on visual and graphical presentations when the frequency of observed data is inadequate for accurate statistical measures.

Acceptance of Model Sensitivity

Sensitivity analysis determines the effect of a change in a model input parameter or variable on the model outcome. The sensitivity of a model parameter is typically expressed as a normalized sensitivity coefficient (Brown and Barnwell, 1987). The methodology for identifying the sensitivity of a model parameter is shown below.

$$\text{Normalized Sensitivity Coefficient (NSC)} = \frac{\Delta Y_o / Y_o}{\Delta X_i / X_i}$$

Where:

ΔY_o = Change in the output variable Y_o
ΔX_i = Change in the input variable X_i

Maine DEP will qualitatively assess the sensitivity of model parameters during manual parameterization (calibration) through parameter perturbation. A summary of model sensitivity will be included in the modeling journal and final modeling report. Details will include the variables modified for model parameterization (calibration), the percent modification (e.g. ± 10%), percent change in the modeling results, and the normalized sensitivity coefficient (Example Table 2-2). The format is shown below.

Example Table 2-2. Sensitivity Coefficient

Model Parameter	% Perturbation	% Change	NSC
Curve Number	-15%	-29%	2.2
Soil Available Water Capacity	20%	25%	1.3
Channel Erodibility	05%	01%	0.1

Algorithmic techniques for sensitivity and uncertainty assessment are available through several water quality modeling programs (Monte Carlo simulation, first-order error analysis, or automated objective function optimization).

Acceptance of Model Uncertainty

Uncertainty is broadly defined as the lack of knowledge regarding model input parameters and the processes the model attempts to describe. Our ability to define model uncertainty is marginalized by our limited ability to accurately describe complex processes. As a result, all engineering computations are attended to a degree of uncertainty due to the simplification of natural process and the limitations of input and parameterization (calibration) data. Computed values differ from observed ones, and the magnitude and frequency of these differences characterize the uncertainty of the best model estimate. Uncertainty analysis is the terminology associated with the examination of how the lack of knowledge in model parameters, variables, and processes propagates through the model structure as model output or forecast error. Sources of model uncertainty are characterized by Maine DEP during the initial stages of planning in order to better understand how the model input data and parameters would potentially influence model output and prediction. Potential sources of model uncertainty include:

(1) Estimated model parameter values.
(2) Observed model input data measurements.
(3) Model structure and forcing functions.
(4) Numerical solution algorithms.

Maine DEP will be responsible for conducting the uncertainty analyses, including statistical procedures in Section 4.2.

1.8 Special Training Requirements

The State of Maine job classification system has established minimum qualifications required for all levels of State of Maine employment. The individuals permanently employed in the sections are either "Environmental Services Specialist", "Engineer" or Biologist". Their qualifications range from a Bachelor's degree to a Ph.D. in one of the natural sciences or engineering. In addition, most of the individuals have a number of years of experience in the field or a closely related field, prior to their employment. Because the State of Maine hiring process establishes training and experience levels required to be employed by these Sections, there is no need to include resumes for each individual in the Sections. The only requirement is that project personnel are expected to read and observe the QAPP.

Certification is not required to operate any of the equipment or to collect water quality samples. To achieve project quality goals, experienced scientists or a limited number of specifically trained assistants will conduct project sampling. Assistants will be either seasonal personnel employed by MEDEP or experienced environmental contractors. Training will be conducted directly by the MEDEP Project Coordinator and consists of:

- Review of the sampling rationale
- Demonstration of sampling equipment, techniques and handling supported by SOPs
- Direct observation of assistant's sample collection methods
- Performance recommendations to increase repeatability
- At least 3 joint site visits to reinforce training and site locations
- Review of preliminary sampling results to critique potential omissions or problems

All training events will be documented in the project files and in the individual training records of DEP staff where applicable.

1.9 Documents and Records

QAPP Modifications. This section addresses procedures to be followed when modifications are needed to a) this Program QAPP, including associated SOPs, or b) any SAP accepted under this Program QAPP that requires real-time modification to achieve project goals. Examples of such modifications include changes in procedures, assessment and reporting.

Discussions involving changes to the Program QAPP may be initiated at any level. Contact should be made with Maine DEP Quality Assurance Manager to determine whether modification is warranted. The scope of effect of the proposed change will determine the formality of the approval process. A formal QAPP modification will include reference to the section(s) of text being modified or added to, the reason why the modification is necessary and the actual replacement/additional language. It will be the responsibility of the Maine DEP Quality Assurance Manager to seek review and approval from others within the agency and from EPA. Signatories of the original Program QAPP will receive such updates for approval. The electronic files will be updated as proposed using annotation that indicates reference to the formal amendment in a designated part of the appendix (e.g., Update I, Appendix 9.10. QAPP Modifications). SOP modifications, additions and retirements follow the same procedure as modifications to the QAPP. Additionally, SOPs must be organized and formatted according to Maine DEP department-wide guidelines. SOPs under development should be included as part of the QAPP as soon as practicable.

Sampling and Analysis Plan Modifications. Modification to project specific SAPs will be made at the discretion of the project manager. In general, modifications that refine details in an existing plan may be dated, signed by the project manager and filed with the plan. Modifications that change the focus and or scope of the projects should be discussed with staff in the section to determine if any changes are necessary at the program level (e.g., and addition or modification of SOPs). If not, the summary of changes should be dated, signed by the project manager and filed with the plan. It is important to note that the purpose of maintaining a record of each project is to maintain metadata associated with the project.

All approved QAPPs shall be reviewed annually by the DEP employee responsible for maintenance of the document, and the results reported to the QAM. Minor revisions shall be documents and incorporated. Substantive revisions shall follow the requirements of OC-QM-002.

Archiving of SAP's. Project specific plans will remain in the possession of the project manager until appropriate reports have been completed. Files associated with such plans will be organized such that persons requesting public information can follow the paper trail from planning through reporting phases in a logical progression. When a project is complete, the original file should be placed in the Section File room in the alphabetical section of folders. Original datasheets need to be filed alphabetically by year among the data folders to facilitate error reconciliation.

Water quality data in the Maine DEP datasets are used for project implementation and decision making. These data are stored on the DEP computer network file server and are backed up onto 2 CDs after major new data uploads. One of these CDs is stored off site in the heated room in the Bureau's equipment storage facility (a/k/a boat house) in Augusta. These data have limitations inherent in storage systems used from 1970 to 1990 when keypunch cards were used to maintain datasets. Paper copies of field sheets from most of these sampling events remain on site so that data integrity questions may be answered immediately. Note: some data sheets may have been lost due to contamination by asbestos being stored in adjacent location in Ray Building attic.

Modeling Journal

A modeling journal will be kept to identify the internal model parameters that were adjusted during the parameterization process to meet the criteria identified in Sections 1.7 and 1.7.2. The journal documents all parameterization iterations made during the project along with the justification and professional reasoning behind the changes. For example, each time that a separate model parameterization run is completed, changes should be documented in the modeling journal. The level of detail in the modeling journal should be sufficient to allow another modeler to duplicate the parameterization method given the same data and model. The modeling journal will include complete recordkeeping of each step of the modeling process. The documentation will consist of information addressing the following items:

- Model assessments and selection with references.
- Model assumptions.
- Parameter values and sources.
- Input file notations.
- Output file notations and model runs.
- Parameterization (calibration) and corroboration (validation) procedures and results from the model.
- Intermediate results from iterative parameterization (calibration) runs.
- Changes and verification of changes made in code, if any.
- Summary of model sensitivity

The modeling journal and report, all data files, source codes, and executable versions of the computer software used in modeling studies will be retained for 10 years in the Section File Room for auditing or post-project reuse. These files will include:

- Version and source of the executable code used.
- Parameterization (calibration) input and output data.
- Corroboration (validation) input and output data.
- Model application input and output (i.e., for each scenario studied).

Documentation of any response action taken to correct model implementation is also described in Section 3.0.

1.9.1 QA Project Plan Distribution

This QAPP will be implemented by Maine DEP once USEPA has given approval. This QAPP is to be considered a "working document". This QAPP will be periodically updated and revised, in accordance with Section 1.9 as technology, policy and protocol change. As required by EPA-NE, an updated QAPP will be formally re-submitted for approval every five years. All QAPP updates will be distributed by the Maine DEP Project Manager according to the distribution list in Section 1.3 and with notification to EPA by the Maine DEP QA Manager.

Upon approval and implementation of this QAPP, the original shall be kept in Division Director's office files. A copy will also be placed in the Maine DEP Library. All personnel responsible for implementation will be required to review this QAPP within 120 days of approval. As new modeling staff or managers are hired by Maine DEP, they will be required to review this QAPP within 90 days of their hiring date. A copy of the QAPP will be placed on the Maine DEP website, and updated as above.

2.0 DATA GENERATION AND ACQUISITION

2.1 Data Acquisition Requirements (Non-Direct Measurements)

Each project manager under this QAPP will be responsible for summarizing how well the data quality objectives (DQOs) were met. The reports to management (Section 4.4) and modeling reports (Section 5.0) will document this activity.

Potential Model Input Data

Water bodies listed on the 303(d) list (designated for TMDLs) should have a historical dataset that has been evaluated using assessment criteria. Water bodies that require the development of Total Maximum Daily Load (TMDL) studies generally receive the most intensive monitoring by DEP staff, contractors, and volunteers trained to do advanced monitoring. The intensity of monitoring generally corresponds to attainment status with respect to water quality standards. Specific annual monitoring designs are found in the annual TMDL Sampling SAP.

SAPs will remain in the possession of each project manager until a project is complete, at which time the document will be filed with copies of results, correspondence and reports produced.

Maine DEP Sections use geographic data derived from U.S.G.S. maps and Maine GIS coverages the latter of which have metadata associated with them detailing limitations. U.S. Census data are available by municipality through the State of Maine Planning Office and is used to evaluate risk of anthropomorphic influences on water quality at the town level. The final responsibility rests with the individual using data and associated geographic information to become aware of the limitations inherent in any information source. These data sources may be used within the section for decisions regarding trend evaluation, use attainment, and as historical background for TMDL projects.

A significant amount of watershed input data may be necessary for setup and parameterization (calibration) of models. Rather than outlining the input data acquisition process, web links to the direct source providers are shown below. Quality information can be viewed in subsequent links, along with information regarding development and disclaimers on use. A majority of the data originates from agencies like USGS, EPA, USDA, Maine DEP and NCDC. The rigor in which these organizations implement QA/QC fully meet the quality objectives identified in this QAPP.

EPA STORET http://www.epa.gov/storet/dbtop.html
National Climatic Data Center (NCDC) http://www.ncdc.noaa.gov/oa/ncdc.html
National Elevation Dataset (NED) http://nris.state.mt.us/nsdi/nris/el10/dems.html
National Hydrography Dataset (NHD) http://nhd.usgs.gov/
National Land Cover Dataset (NLCD) http://landcover.usgs.gov/index.asp
National Water Information System (NWIS) http://waterdata.usgs.gov/nwis/
Remote Automated Weather Stations (RAWS) http://www.fs.fed.us/raws/
Snow Telemetry (SNOTEL) http://www.wcc.nrcs.usda.gov/snotel/
STATSGO Soils http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/

Flow and water quality parameterization (calibration) data are also subject to the DQOs identified in Sections 1.7 and 1.7.2. Sources of effluent, discharge, and in-stream water quality data will have an approved QAPP from Maine DEP and or the U.S. EPA. Data with unknown quality (i.e. collected without a documented QAPP or using unapproved SOPs) will be flagged and noted as either conditionally acceptable for limited use or not acceptable for use at all. Best professional judgment is used to exclude data from the dataset. Additional procedures to ensure consistency in excluding data, outdated data or otherwise, include the following:

- Data which is older than twelve (12) years old may be excluded.
- Data from other outside agencies without proper QA may be excluded.

2.2 Data Management

The general approach to data storage and retrieval of electronic media is as follows:

- Data are saved on the network servers.
- Data are backed up onto CD and stored offsite.

The following data handling equipment, hardware and software are used.

- Maine DEP network servers.

Potential Model Input Data

Water quality data are entered on standard field forms that are often updated annually. Data are entered into databases through various means. Most of the data are entered into electronic files (dbf) before arriving at Maine DEP.

Maine DEP project staff proof all of the data. Data are proofed for transcription errors. Quality control readings are examined. Best professional judgment is used to exclude data from the dataset. Proofed sheets are initialed and dated by the proof reader. Corrected files or file sets are merged into one or two large data sets and a number of error checking procedures are performed to validate that the water body identification number was used, that parameters are within an expected range (primarily a check for decimal point errors) and that dates have been handled properly (to identify conversion errors). Data are uploaded to 'master files' on the network thereafter. Write access to these files is restricted. Data collected prior to 2008 currently reside in Maine DEP network servers files that are not truly relational. Data collected in 2008 and later will be entered into Maine's Environmental and Geographic Analysis Database (EGAD). Proofed sheets are initialed and dated by the proof reader.

Model Application Data

Standard parameterization (calibration) and data management procedures will be implemented during modeling projects to ensure that modeling results are valid, reproducible, and comparable. The standard procedures include the following: (1) use of modeling techniques accepted within the profession, (2) parameterization (calibration) methods that can be performed repeatedly by a qualified person to obtain similar results, (3) documentation that is clear, concise, and thorough, and (4) the use of standard units for data management.

Data used during modeling projects will be maintained in either hard copy or electronic format – depending on the nature of it. As a result, database entry and manipulation within a model is identified as one of the major preventable error sources in the modeling effort. Unlike the limitations of the model and model driver data itself, user induced error is correctable under an appropriate level of QA/QC. Multiple steps will be taken to ensure errors are minimized. Data formatting will be reviewed prior to the final version of the database being generated, including the data element type, format, allowable values and ranges, and other parameters. All data used to populate the modeling database will be screened before upload to the model application. Manually entered parameter values from paper sources will be evaluated by reviewing printouts of summaries and randomly selecting portions of the model application. The review will include a comparison of the original data sources and paper documentation. Any record identified as having problems will be reviewed to determine whether corrected data can be acquired or the record omitted in accordance with Section 2.1. The model input files will be checked by Maine DEP for reasonability and correctness in order to detect errors that may occur during the data management or transfer process.

3.0 ASSESSMENT AND OVERSIGHT

3.1 Assessments/Oversight and Response Actions

The data generated as part of the modeling results will be evaluated during the corroboration (validation) process. Model performance assessments will be made continually by Maine DEP as described in the parameterization and corroboration processes in Sections 4.1 and 4.2. Performance audits will consist of review of technical memoranda comparison of model results with observed historical data, and general evaluation of model behavior for state variables and other output lacking historical data. Auditors may include the Maine DEP QA Manager or Section Manager who are authorized to stop work, for good cause.

At the end of the parameterization and corroboration period, the Maine DEP will assess the ability of the model to predict hydrologic and water quality response over time. Section 1.7.2 identifies criteria that will be part of the model performance assessment and also assessed are:

- Modeling input and output validity.
- Model parameterization and corroboration performance determinations.
- Sensitivity and uncertainty analysis assessments.

Parameter deviation and post-simulation corroboration of predictions are major issues in the quality assurance framework. Maine DEP will document the model data entry, parameter estimation, and parameterization activities, and will provide this documentation as part of the modeling journal, model report and the project file. A typical Maine DEP internal assessment is described below.

Modeling data, and project deliverables, will be internally quality-checked by Maine DEP in-house review. Anticipated Maine DEP review staff members responsible for this process include the Project Manager and QA Manager. The Project Manager will maintain overall responsibility for examining the work to ensure that methodologies and processes are consistent with the procedures outlined in the QAPP. He or she will provide advice to the QA Manager of any deviations from the QAPP so that appropriate actions may be taken either to correct the problem, or amend the QAPP as needed. The QA Manager will monitor the extent to which the QAPP is supporting its intended use. Other expertise will be called in, as required. If the quality control audit results in detection of unacceptable conditions or data, the Project Manager will be responsible for developing and initiating corrective action. Corrective response actions may include:

- Review or corroboration of modeling input and parameterization data.
- Re-definition of model extents or spatial distribution.
- Performing additional model runs.
- Editing and modifying report deliverables.

4.0 MODEL APPLICATION

4.1 Model Parameterization (Calibration))

All models, by definition, are a simplification of the environmental processes they intend to represent. The optimization of empirical parameters that form the numerical basis of the model is referred to as parameterization (calibration). Parameterization iteratively adjusts model coefficients or parameters until predicted values accurately reproduce those measured in the field. Some models have internal parameterization tools that aid the user in managing parameterization scenarios and refining model runs until acceptable parameterization criteria are met. Once an acceptable parameterization is reached, the run can then be verified on an independent data set to judge the extent to which the model is able to predict hydrologic or water quality conditions over time.

A complete watershed model parameterization involves a successive examination of the following characteristics of the watershed hydrology and water quality: (1) annual and seasonal water balance and streamflow, (2) sediment, and (3) nutrients. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement. The refinement of parameters should reflect the scientific literature and not exceed reasonability. The rationale for any model adjustments should be based on the parameterization procedures outlined in the QAPP and documented in the modeling journal and report.

Parameterization Considerations

Parameterization should consider the most important hydrologic and water quality response variables. The sensitivity of these parameters has a significant influence on the uncertainty of the model and should be equally considered during the parameterization process. Ideally, both high and low flow years, and the anticipated range of conditions and scenarios for which the TMDL will be developed will be used. Criteria for defaulting to non site-specific data include the following:

- Site specific data will be used at all times.

Considerations for which parameters to keep constant include the following:

- Similar hydraulic conditions.

Parameterization should be completed in sequential order, using the most upstream point first and then moving downstream to the next point of parameterization (calibration). It is important that parameters of files associated with the drainage area upstream of a calibrated point, are not changed during subsequent steps.

Parameterization Stop Criteria

Stop criteria can be useful to prohibit never-ending parameterization and allow the introduction of more subjective criteria, if necessary. This can stop the "ever decreasing circles" that some optimization methods tend to follow in search of an exact minimum in the objective function (European Commission 2005). In consultation with the Section Manager, a prioritized list of stop criteria includes the following:

- available resources
- a specified end date
- a specified maximum number of model runs
- a specified change in size of a function value (objective function, parameter values, etc.) towards an apparent minimum.

Any deficiencies during the parameterization process are worked through the Section Manager and documented in the modeling journal and report. See also Section 4.4.

Following parameterization, verification on an independent data set is necessary to evaluate the effectiveness of the model to represent physical processes beyond those for which the model was calibrated. Decisions made during model parameterization and verification will be documented in the modeling journal and report so that an experienced user could complete the parameterization process and obtain similar modeling results. See also Section 1.7 Quality Objectives and 1.7.2 Performance Criteria.

4.2 Model Corroboration (Validation and Simulation)

Criteria used to review/validate data are listed in Sections 1.7, 1.7.2 and here. Best professional judgment will also be used in conjunction with these criteria.

Once an acceptable parameterization is reached, the model corroboration (validation) is run on an independent data set to judge the extent to which the model is able to predict hydrologic or water quality conditions over time.

The quality of the model fit is examined by: 1) the coefficient of determination (r^2) of the linear regression between simulated and observed; 2) the coefficient of model-fit efficiency, which measures the proportion of variance in the observed as explained by the simulated (Nash and Sutcliffe, 1970). The coefficient of determination (r^2) and the coefficient of model-fit efficiency are similar because both provide a measure of the variation in the simulated value explained by the observed value. The coefficient of model-fit efficiency, however, provides a more rigorous evaluation of the fit quality than does the (r^2) because the model-fit efficiency measures the magnitude of the differences between simulated and observed values, whereas the (r^2) measures the difference between the mean values (Duncker and Melching, 1998). In cases were the observed values and model residuals are normally distributed, the value of the (r^2) and the model-fit efficiency should be equal. The difference between simulated and observed values may also be reported as the (1) standard error, in ft^3/s; (2) root mean square error, in percent; (3) percent of time differences were within 10 percent, and (4) percent of time differences were within 25 percent; (5) median percent error, (6) minimum percent error, and (7) maximum percent error.
See also Section 1.7. and 1.7.2

Models for Comparative Analyses

Occasionally, comparative modeling is used to evaluate potential water flow and water quality benefits from combinations of storm water management practices and designs that have yet to be implemented. A cost benefit analysis of varying designs and design combinations may be the basis for this type of modeling. In these instances, the following will be addressed and included in the modeling report.

- Definition of the Base Line Conditions - the specific conditions, parameters and values that define the baseline condition.
- Criteria for Comparisons - the terms for comparing the model simulation results to the base line condition. For example, the terms may be found in quantities or percentages of runoff, infiltration or storm water contaminant loads.
- Identify Significant Change from Baseline - the application of statistical tools and criteria used to determine if there are significant differences between the baseline condition and model simulation results.
- Identify Simulation Scenarios from Sensitivity Analysis - how the simulation scenarios take into account what is understood from the model sensitivity analysis.
- Corroboration of Model Outputs - use of literature searches, calculations and the growing number of storm water performance databases to "ground truth" the projected water flow and/or water quality benefits from storm water management designs. Some examples include the following:

EPA Urban Best Management Practices Performance Tool
http://cfpub.epa.gov/npdes/stormwater/urbanbmp/bmpeffectiveness.cfm

University of New Hampshire Stormwater Center
http://www.unh.edu/erg/cstev/pubs_specs_info.htm

University of Massachusetts Stormwater Technologies Clearinghouse http://www.mastep.net/

International Stormwater Database http://www.bmpdatabase.org/

National Pollutant Removal Performance Database, September 2007
http://www.cwp.org/Downloads/bmpwriteup_092007_v3.pdf

Center for Watershed Protection http://www.cwp.org/PublicationStore/special.htm#pollut2

Boston Metropolitan Area Planning Council - Massachusetts Low Impact Development Tool Kit
http://www.mapc.org/regional_planning/LID/LID_Links_References.html#national

EPA Low Impact Development Literature Review http://www.epa.gov/owow/nps/lid/lid.pdf

and: http://newmoa.org/prevention/webconferences/stormwaterweb/stormwaterresources.pdf

4.3 Reconciliation with User Requirements

Maine DEP is committed to developing a representative modeling product and will ensure that: (1) complete documentation is maintained, (2) departures from corroboration (validation) criteria are addressed, (3) corroboration (validation) methods are properly documented, and (4) the modeling data are properly reviewed. In this context, reconciliation with user requirements connotes establishing how model results will be tested and evaluated in order to ensure that the models are producing results of sufficient quality.

As part of the reconciliation process, the model deliverables (modeling reports, technical memoranda, etc.) will be reviewed by the Maine DEP Project Manager to assess whether the quality requirements of the QAPP have been met. A comprehensive review of the final model files and documentation will be completed and recommendations provided regarding the effectiveness of the model to be used in watershed planning and TMDL decision-making. The determination will largely be based on the effectiveness of the model to predict hydrologic and water quality response.

Each project manager under this QAPP will be responsible for summarizing how well the data quality objectives (DQOs) were met, including whether there have been departures from the assumptions in the planning process. Any significant departures from the QAPP and initial assumptions will be reported to the Section Manager. See also Section 4.4.

4.3.1 Model Limitations and Final Evaluation Criteria

It should be noted that all models are a simplification of the environmental processes they intend to represent. Although there is no consensus on model performance criteria in the literature, a number of basic statements are likely to be accepted by most professional modelers.

• Models are approximations of reality and cannot precisely represent natural systems.
• There is no single, accepted test that determines whether or not a model is validated.
• Models cannot be expected to be more accurate than the sampling and statistical error (e.g., confidence intervals) in the input and observed data.

These considerations must be included in the development of appropriate procedures for quality assurance of the models. Despite a lack of agreement on how models should be evaluated, the following principles provide a final set of evaluation criteria for the modeling projects.

• Exact duplication of observed data is not possible, nor is it a performance criterion for projects. The model corroboration (validation) process will measure the ability of the model to simulate measured values.

• No single procedure or statistic is widely accepted as measuring, or capable of establishing, acceptable model performance. Therefore the combination of graphical comparisons, statistical tests and professional judgment are proposed to provide sufficient evidence upon which to base a decision of model acceptance or rejection.

• All model and observed data comparisons must recognize, either qualitatively or quantitatively, the inherent error and uncertainty in both the model and the observations. Model sensitivity and uncertainty will be documented, where possible, as part of each modeling study.

A margin of safety will be built as part of the modeling process to blanket model limitation and assumptions, and gage the impact on the usability of the results toward decision-based management. This will be addressed in the modeling report. See Also Section 1.7.2.

Staff should be alerted to the importance of documenting the modeling limitations, assumptions, and margin of safety built into the modeling process. The Clean Water Act statue and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between the load and wasteload allocations and water quality. If conservative assumptions are made in the analysis and modeling process that account for the MOS, this implicit MOS must be described for future use in the TMDL report. Otherwise, the TMDL must identify an explicit MOS (e.g. expressed in the TMDL as loading set aside for the MOS.

4.4 Reports to Management

Existing Data

TMDL reports include: a water body description, watershed GIS assessment and estimation of pollutant sources, identification of a total target goal (acceptable amount), allocation of watershed/land-use loadings, and uncertainty concerns and seasonal variation. These reports include a public participation component to allow for public review prior to submission to EPA.

An Integrated Water Quality Report is submitted to EPA on a biannual cycle. This satisfies reporting requirements in Sections 314, 305(b) and 303(d).

Model Application Data

The Maine DEP Project Manager will report the status of project activities at the end of each month to the Section Manager. Problems encountered during performance evaluations, system assessments and data quality evaluations will be identified and appropriate corrective actions will be determined and implemented, if necessary. These problems and corrective actions will also be documented in the modeling journal and final modeling report.

5.0 MODELING REPORTS

Modeling Reports will contain the following information, if applicable. Where not applicable, an explanation will be provided. An example of a modeling report used in the past that contains much of the information below is included in Appendix A.

Describe the content of modeling reports as including each of the following:

Introduction and Background
- Watershed map(s) with extent of impaired segment(s) and location of monitoring stations
- Land use/land cover map, if applicable

Water Quality Model

Purpose of Modeling/Modeling Objectives *(Note: Missing in Appendix A-Example Report)*
Scope and Approach for Each Model Used (including):
Physical Setting (and Hydrology, if applicable)

Observational Data Used to Support Modeling
Quality of Acquired Data (and references to data quality reports)
Achievement in Meeting Acceptance Criteria *(Missing in Example Report)*
References to Monitoring Data
Discussion on Excluded Data and Basis for Exclusion *(Missing in Example Report)*

Model Configuration (discusses how model was applied, including):
Spatial and Temporal Resolution *(Missing in Example Report)*
Nature of Grid, Network Design or Sub-watershed Delineation
Application of Sub-models
Model Inflows, Loads and Forcing Functions
Key Assumptions (associated limitations, if any) *(Missing in Example Report)*
Changes and Verification of Changes Made in Code, if any

Water Quality Model Transport and Chemical Parameterization (calibration)

Model Parameterization (calibration)) and Corroboration (validation)
Objectives, Activities and Methods
Parameter Values and Sources
Rational for Parameter Values Estimated in the Absence of Data
Parameterization Variables and Targets *(Missing in Example Report)*
Measures of Parameterization Performance

Model Load Inputs

Parameterization (calibration) Input, Output and Results Analysis
Model Corroboration Results

Model Prediction Runs

Model Use Scenario Analysis and Results (should relate to purpose)
Output of Model Runs and Interpretation
Summary of Assessments and Response Actions, if any
Soundness of the Parameterization, Corroboration and Simulations
Review of Initial Assumptions and Model Suitability Evaluation *(Missing in Example Report)*
Performance Against the Performance Criteria Including:
Model Parameterization and Corroboration *(Missing in Example Report)*

Model Sensitivity Analysis and Components of Impact

Model Sensitivity and Uncertainty Analyses *(Missing in Example Report)*
Pre- and Post-Processing Software Development, if any

Maps, Photographs and Drawings (if appropriate)
Deviations from the QAPP Including a List of Non-Applicable Reporting Elements with Explanations *(Missing in Example Report)*
Conclusions
Recommendations
References and Appendices *(Missing in Example Report)*

6.0 USEFUL REFERENCES

ASTM. 1984. Standard Practice for Evaluating Environmental Fate Models of Chemicals. Designation E978-84. American Society of Testing and Materials. Philadelphia, PA. 8 p.
Brown, C.L., and T.O. Barnwell, Jr. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS – Documentation and User's Manual. Environmental Research Laboratory. EPA/600/3-87/007. Athens, GA.
Donigian, Jr., A.S. 1982. Field Validation and Error Analysis of Chemical Fate Models. In: Modeling Fate of Chemicals in the Aquatic Environment . Dickson et al. (eds.), Ann Arbor Science Publishers, Ann Arbor, MI. 303-323 p.
Duncker, J.J. and Melching C.S., 1998, Regional rainfall runoff relations for simulations of streamflow for watersheds in DuPage county, Illinois: U.S. Geological Survey Water-Resources Investigations Report 98-4035, 80 p.
Diskin, M.H. and Simon, E. 1977. "A procedure for the selection of objective functions for hydrologic simulation models." Journal of Hydrology, 34, 129-149.
European Commission, 2005 – Harmonising Quality Assurance (HarmoniQuA) in model based catchment and river basin management. http://harmoniqua.wau.nl/
James, L.D. and S.J. Burges. 1982. Selection, Calibration, and Testing of Hydrologic Models. In: Hydrologic Modeling of Small Watersheds. ASAE Monograph No. 5. C.T. Haan, H.P. Johnson,
D. L. Brakensiak (eds). American Society of Agricultural Engineers, St Joseph, MI. Chap 11. pp 437-474.
Maine DEP. 2004. Maine Lake Assessment Quality Assurance Project Plan. August.
Montana DEQ. 2005. Bitteroot Soil Water Assessment Tool (SWAT) Model Quality Assurance Project Plan. Montana Department of Environmental Quality-Water Quality Planning Bureau, Data Management Section. March.
http://www.deq.state.mt.us/wqinfo/Modeling/SWAT%20MODELING%20QAPP-REV2.pdf
Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models; Part-I, A discussion of principals: Journal of Hydrology, v. 10, p. 282–290.
Thomann, R.V. 1982. Verification of Water Quality Models. Jour. Env. Engineering Div. (EED) Proc. ASCE, 108:EE5, October.
U.S. EPA. 2002. QA/G-5M - Guidance for Quality Assurance Project Plans for Modeling. EPA/240/R-02/007- December. http://www.epa.gov/quality/qs-docs/g5m-final.pdf
U.S. EPA Region I. 2007. Draft Generic Modeling Quality Assurance Project Plan Template, June. http://www.epa.gov/region1/lab/qa/qamodeling.html
US Geological Survey. 2007 - Draft Quality Assurance Project Plan for Modeling Effects of Low-Impact Development on the Hydrology of the Upper Ipswich River Basin, MA

Appendix A

Penobscot River Modeling Report

Draft

April 2003

Paul Mitnik, P.E.

Bureau of Land and Water Quality

Division of Environmental Assessment

DEPLW-0582

Executive Summary

1. A study of the Penobscot River from Millinocket to Bucksport (103 miles) began in the summer of 1997 involving the DEP and a number of stakeholders such as the Penobscot Nation, Great Northern Paper, International Paper, USEPA, and the Lincoln Sanitary District
2. Data was collected in the summers of 1997 and 2001 to calibrate and verify a water quality model. The lack of runoff prior to the survey, presence of low flow conditions (about 5 year low flow and 97% flow duration), and utilization of good QA/QC measures resulted in excellent quality data to calibrate the water quality model.
3. Non-attainment of class B dissolved oxygen criteria was observed at only one location in 1997, but at ten of fourteen locations sampled in 2001. Chlorophyll a results exceeded the algae bloom threshold (8 ug/l) at only one location in 1997 but five of the fourteen locations sampled in 2001. For detailed descriptions of the data, one should consult the Penobscot River Data Report (MDEP, April 1998 and May 2002).
4. MDEP's version of the EPA supported model, QUAL2EU, (QUAL2MDEP) was used to model the Penobscot River and estuary. Some of the important changes to QUAL2EU include the addition of a periphyton module and benthic BOD component, an enhanced dissolved oxygen saturation calculation that adds salinity as a dependent variable, and alteration to phosphorus output units to the nearest 0.1 ppb.
5. The model was calibrated and verified with comparisons of the model output of salinity, BOD, phosphorus, nitrogen, chlorophyll-a and dissolved oxygen to the data observed in the summers of 1997 and 2001. Good comparisons resulted. All values assigned as parameter rate inputs were within recommended ranges in the literature. The model is considered to be a good predictive tool for estimating river dissolved oxygen and algae levels.
6. The model run at worse case conditions of 7-day-10-year low flow (7Q10), high water temperatures, and point sources at licensed loads predicts that minimum dissolved oxygen criteria (7 ppm) will not be met in approximately 51 class B river miles or about ½ of the 103 miles modeled. In addition algae blooms are projected to occur in about 25 miles or about ¼ of the 103 miles.
7. Point sources account for about 74% and 94% of the total BOD and phosphorus loads, respectively, that enter the Penobscot River. Paper mills are about 80% and 70% of the total point source loads for BOD and phosphorus, respectively.
8. A component analysis was undertaken at three strategic points on the river to determine the causes of dissolved oxygen depletion. The following causes were determined to be the most significant:

    <u>Above Rockabema Dam</u> – Sediment Oxygen Demand (37%) and Background (37%)
    <u>Passadumkeag - Greenbush</u> – Point Source Nutrients (45%) Sediment Oxygen Demand (35%)
    <u>Orrington</u> – Point Source BOD (43%) and Sediment Oxygen Demand (37%)

9. Point source reductions of 60% for BOD5 from current licensed amounts (slightly higher than actual performance levels) and reductions of 40% of total phosphorus from actual levels are needed to achieve dissolved oxygen criteria on the entire 103 mile segment. Algae blooms would also be eliminated with these reductions

10. There are many methods that could be used to allocate point source reductions. The following is offered as a starting point for discussions on how to implement point source reductions in waste discharge licenses.

Table 14 Point Source BOD5 and Phosphorus Allocation Municipal Discharges

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by current discharge	Allocate by equal concentration
Millinocket	180 / 200	210 / 230	28	24
Lincoln	50 / 55	90 / 100	12	10
Old Town	400 / 480	220 / 250	36	26
Orono	100 / 110	180 / 200	18	21
Veazie	16 / 18	28 / 31	3	3
Bangor	900 / 1000	1470 / 1630	212	169
Brewer	230 / 250	620 / 690	15	71
Winterport	Primary Plant		No Restriction	
Bucksport	Primary Plant		No Restriction	

Paper Mills

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by equal % Reduction	Allocate by equal concentration
GNP West	8200 / 10800	8700 / 11500	96	87
GNP East	1450 / 2600	1800 / 3200	97	88
E Paper Lincoln	5000 / 6800	2700 / 3700	30	45
G Pacif Old Town	3600 / 5100	4000 / 5600	63	66
IPCo Bucksport	7100 / 10000*	No Restriction		

* Current licensed levels

Table of Contents

Tables

Introduction

The Penobscot River Basin is the largest river basin lying entirely within the State of Maine. It has a drainage area of 8592 square miles at its mouth. The river segment of interest on the Penobscot River begins in Millinocket below Ferguson Lake as the West Branch, where after 10 miles it joins with the East Branch. It then flows an additional 69 miles before reaching head of tide at the Veazie dam, and then over 24 additional miles of tidal waters to Bucksport. In this 103-mile segment, there are 15 point source discharges, 11 dams, and 9 tributaries that have a drainage area of over 100 square miles. A list of dams and point sources are illustrated in tables 1 and 2.

The Penobscot River model is a result of an ongoing effort by DEP and stakeholders. A model for this 103 mile segment was first set up by DEP in 1991 (Penobscot River Basin Waste Load Allocation, Jan 1991). This report revealed that the river was at its limit for receiving point source discharges while still maintaining water quality standards.

The effort undertaken from 1997 to current updates the model to modern conditions. Two separate Penobscot River Data Reports (April 1998, and May 2002, MDEP) discuss the data that were collected by DEP and a number of stakeholders such as the Penobscot Nation, Great Northern Paper, International Paper, USEPA, and the Lincoln Sanitary in the summers of 1997 and 2001. The 1997 data were collected to calibrate the water quality model. The Penobscot River Modeling Report (June 2000) discusses the modeling effort derived from the calibration (calibration) of the model to the 1997 data. This modeling effort revealed that the Penobscot River was beginning to develop some water quality non-attainment issues (lower than required dissolved oxygen and algae blooms). An additional data set for model verification was recommended in the summer of 2001 to more accurately assess the situation and consider cleanup alternatives. This report represents the final recommendations for the Penobscot River based upon a completed modeling effort.

Summary of 1997 and 2001 Data

The overall quality of both the 1997 and 2001 data are considered excellent due to good QC measures utilized throughout the sampling effort that involved such practices as cross checking of dissolved oxygen meters and duplicate sampling. The three-day intensive surveys were undertaken on August 5, 6, and 7 of 1997 and August 7, 8, and 9 of 2001 and were specifically for calibration (calibration) and verification of the water quality model. It is desirable to collect the model calibration (calibration) data sets under conditions of low flow and high water temperature. This represents conditions of worse case when river dissolved oxygen levels are most likely to be the lowest. At lower river flow, the dilution of waste loads is reduced resulting in river pollutant concentrations of higher strength. At high water temperatures, dissolved oxygen saturation decreases and the biological activity increases resulting in a greater amount of oxygen demand in the water column as BOD (biochemical oxygen demand) and greater amount of oxygen demand from bottom sediments (SOD). Thus water column dissolved oxygen depletion is maximized under these conditions.

A goal of sampling at less than 4400 cfs as measured at the USGS gage in West Enfield (90% flow duration) was used as a target flow for the three-day intensive survey. This goal was met in both intensive surveys. The three-day average flow was 3620 cfs in 1997 and 3400 cfs in 2001. Both data sets represent about a 97 % flow duration or about a 5-year low flow event.

Another preferable sampling condition is having no runoff during and prior to the survey. Runoff is undesirable due to the difficulty of quantifying it as input to the model. One of the water quality model's underlying assumptions requires steady state conditions. This would not be met if significant runoff occurred during or two to three days prior to the sampling event. There was no runoff three weeks prior to August 5, 6, 7 of 1997 and no runoff ten days prior to August 7, 8, and 9 of 2001.

The upper 22 miles of the study reach from Millinocket to the confluence of the Mattawamkeag River (River Miles or RM 83 – 61) are classified C requiring minimum dissolved oxygen to not be less than 5 ppm and 60 % of saturation. Six locations were sampled in this class C reach for dissolved oxygen and temperature. The next 67 miles from the Mattawamkeag River to Reeds Brook in Hampden (RM 61 to –6) are classified B waters with the exception of 1 mile directly above the Enfield dam (RM 38 to 37) which is classified C. Fourteen locations were sampled for dissolved oxygen and temperature in the class B reach and one location in the class C reach above the Enfield dam. Class B waters require that a minimum dissolved oxygen level of 7 ppm and 75% of saturation be maintained at all times. The final 22 miles of the study reach are tidal waters and are classified SC. Nine locations were sampled for dissolved oxygen and temperature in the class SC reach. Class SC requires that minimum dissolved oxygen of 70% of saturation be maintained at all times.

The 1997 data indicated that minimum statutory dissolved oxygen criteria were met and often greatly exceeded at all locations, except North Lincoln, where minor non-attainment of class B dissolved oxygen criteria sometimes occurred. Of significance, however was the fact that point source discharges were at only 10% of their licensed permitted BOD5 (five-day biochemical oxygen demand[1]) limits. Hence the potential for lower dissolved oxygen levels than measured is possible, and worse case levels must be determined by the model. The 2001 data indicated that dissolved oxygen criteria were not met in 10 of the 14 locations sampled in class B waters.

---

1 Biochemical oxygen demand (BOD) is a laboratory test estimating the amount of oxygen demanding substances in water samples. The oxygen depletion of a water sample is measured over a time increment. The five-day test or BOD5 is typically used to measure BOD in effluent samples from wastewater treatment plants. Hence, this test measures the potential of discharges to deplete oxygen within a river.

About 50 river miles are estimated to currently not attain class B minimum dissolved oxygen criteria. The BOD5 discharged by point sources was about 17% of licensed amounts during the 2001 sampling event. In class C and class SC waters, the 2001 data indicate that dissolved oxygen criteria were maintained.

A chlorophyll-a[2] level of 8 ug/l is used as a threshold level indicating the occurrence of an algae bloom. When chlorophyll a levels approach this threshold, the water may begin to appear green tainted from plankton that are floating in the water. The plankton may also be visible within the water column. Only one location exceeded 8 ug/l in 1997; the average three-day chlorophyll a was 9 ug/l at the Weldon dam. Other locations at Dolby dam and three locations within the estuary had levels approaching 8 ug/l. The data and modeling reports indicated that a eutrophication problem on the Penobscot River could be forthcoming.

The 2001 data indicates a further deterioration in eutrophic state in the Penobscot. Chlorophyll a levels exceeded the threshold of 8 ug/l at five of the fourteen locations sampled; including above Dolby, Rockabema, and Weldon dams on the West Branch and upper Penobscot and Orrington center and South Orrington in the estuary.

Both the chlorophyll-a levels and dissolved oxygen readings indicate deterioration in water quality when compared to the 1997 data. Conditions of river flow, water temperature and waste load inputs were examined as an initial attempt to explain the lower water quality experienced in 2001. River flow was not significantly different in both data sets (3620 Vs 3400 cfs at Enfield in 1997 and 2001, respectively).

A comparison of point source inputs (Figure 1) indicates that point sources discharged higher amounts of pollutants in 2001 when compared to 1997. Point sources collectively were discharging 739 ppd. of total phosphorus in 1997 and 1250 ppd. of total phosphorus in 2001 representing an increase of 69%. Point sources collectively were discharging 30,600 ppd. of total ultimate BOD[3] in 1997, and 45,300 ppd. of total ultimate BOD in 2001 representing an increase of 48%.

A comparison of water temperature (figure 2) indicates that levels in 2001 were typically 3 to 4 $^{\circ}$C higher than 1997. As explained earlier in the text, higher water temperatures generally result

---

2 The chlorophyll-a test is used as an indicator to quantify the amount of phytoplankton or floating algae within a water sample.

3 The ultimate BOD test (UBOD) involves observing oxygen depletion in a water sample in a laboratory over a period of 60 days or more until nearly all of the oxygen demand is utilized. It is a more accurate representation of oxygen demand than the five-day test, and is typically used in modeling studies. The five-day test was originally thought to capture about 60% of the total UBOD, but studies have shown that the five-day test typically captures much less than 60% of the UBOD. Total ultimate BOD (TBODu) is the sum of both the carbonaceous and nitrogenous components of BOD.

in lower dissolved oxygen. Higher water temperatures also result in conditions more favorable for algae growth.

The higher water temperatures, and higher inputs of BOD and phosphorus collectively result in lower dissolved oxygen at virtually all locations in 2001 than 1997 (figure 3). The higher levels of algae can be explained by the higher phosphorus inputs and higher water temperatures. Algae creates a diurnal cycle of the lowest dissolved oxygen in the early morning after extended respiration and the highest dissolved oxygen in mid to late afternoon during extended photosynthesis and respiration. A larger range (diurnal dissolved oxygen) of the AM and PM dissolved oxygen readings usually indicates more algal activity. The larger diurnal dissolved oxygen in the 2001 data is evident when compared to the 1997 data (figure 3).

Water Quality Model

The EPA supported model, QUAL2EU was used in the analysis of the Penobscot. Steady state flows and load inputs are required and major transport mechanisms of advection and dispersion must be one-dimensional. The lack of runoff that was previously discussed satisfies the steady state condition. The uniformity of the dissolved oxygen and temperature readings in the vertical profiles indicates that the Penobscot is a well-mixed system and hence one-dimensional flow occurs. The Penobscot River should be well suited to this model.

Many changes were recently incorporated into MDEP's version of QUAL2EU or more appropriately named QUAL2MDEP. The changes are as follows:

1. Addition of a periphyton module with links to the nutrient and dissolved oxygen modules. A major shortcoming of QUAL2EU is bottom attached algae can not be directly modeled. The majority of impacts now experienced in rivers involve low early morning dissolved oxygen from bottom attached algae. The QUAL2MDEP model can now be used to model bottom attached algae and the resulting diurnal dissolved oxygen swings.
2. Addition of a benthal BOD component. QUAL2EU models the direct oxygen demand from bottom sediments, but the sediment may also add BOD to the water column. This is particularly significant in long river systems like the Penobscot with long travel times to accurately model non-point source impacts. This was identified as a deficiency in QUAL2EU (see page 6, Penobscot Modeling Report, June 2000).
3. Enhancement of the dissolved oxygen saturation calculation. QUAL2EU calculates dissolved oxygen saturation as a function of temperature. This results in unnecessary error in marine situations, since salinity also affects dissolved oxygen saturation. Salinity is now included into the dissolved oxygen saturation calculation.
4. Alteration to phosphorus output units. QUAL2EU's output for organic phosphorus and dissolved phosphorus is rounded off to the nearest 10 ppb. This has been changed in

QUAL2MDEP so the output for phosphorus components are now rounded off to the nearest 0.1 ppb.

5. Revisions to the simulation output formats. The diurnal output was enhanced so that all dynamic output can now be observed. An EXCEL VBA post processor was created. The output for a dynamic model run is quite large and not easily managed. The postprocessor allows the selection of specific output specified by the user, which can be transferred to an EXCEL spreadsheet for observation and easy plotting.

The model reach structure was set up identical to the 2000 modeling effort. The model has 39 reaches, and 34 point source inputs (figure 4). In the model non-point source tributary inputs are modeled as point sources. There are 15 point source inputs and 19 tributary inputs. The estuary was simulated as a tidally averaged steady state model. Phytoplankton as chlorophyll-a, nutrients as nitrogen and phosphorus, carbonaceous BOD, periphyton, and dissolved oxygen were simulated as the chemical parameters of interest.

Model Transport

In the hydraulic component of the model, river velocity and depth relationships are developed as a function of flow. Transect and time of travel data are used as a basis for deriving the relationships. QUAL2EU offers two options for the transport of pollutant parameters; a power equation and the Manning equation for open channel flow. The power equation option was chosen for the Penobscot River model. This computes velocity and depth as a function of flow with the following equation:

$$\mathbf{V = A_1 Q^{B}{}_1 \quad and \quad D = A_2 Q^{B}{}_2}$$

Where:
V = velocity;
D = depth;
Q = flow, and
A_x, B_x are coefficients that are empirically derived from transect and time of travel data

The hydraulic coefficients were already calculated from a previous MDEP modeling effort (see Penobscot River Basin Waste Load Allocation, P. Mitnik, 1991). No changes were made to the 1991 model hydraulic coefficients (table 3).

Dispersion or longitudinal spreading becomes very significant in the estuary and must be appropriately considered. A conservative parameter such as the salinity data is generally used to calibrate the dispersion rates to use in the estuary. Initial estimates of dispersion can be obtained by plotting Ln salinity Vs river mile. The dispersion is then the estuary advective or flushing velocity divided by the slope of the Ln salinity Vs river mile. Initial estimates of dispersion rates used in the estuary ranged from 5 to 150 mi^2/day and resulted in a good fit of the salinity data to measured values (figure 4a, 5, table 4).

Flow data areavailable at a number of locations throughout the Penobscot River watershed. USGS gages that were used include the Penobscot River at West Enfield; Mattawamkeag River at Mattawamkeag; and Piscataquis River at Medford. A flow balance was calculated for the watershed (table 5) using this available flow information and a proration of watershed drainage area for tributary inputs to the Penobscot. The larger tributaries were input to the model as point sources and the smaller tributaries were grouped as incremental flow inputs or distributed loads.

Chemical Calibration of the Water Quality Model

The chemical calibration of the model involves inputting measured tributary and treatment plant effluent as point source loads, measured upstream and downstream boundary conditions and measured water temperature as initial conditions. The model output of various parameters, such as BOD, chlorophyll a, and dissolved oxygen are compared to measured values and adjustments are made to the model parameter rate coefficients until a good match of model and observed data occur. The model parameter rates that are adjusted include many inputs (see Tables 6, 7). Default values are used as initial estimates and adjusted within the ranges recommended in the literature until satisfactory results are achieved. The model is verified after satisfactory results are obtained from a comparison of modeled Vs observed data of a second independent data set. After this process, the model can then be reliably used for model predictions of water quality.

The 1997 data collected on August 3, 4, and 5 were used to calibrate the Penobscot River water quality model. This is discussed in the 2000 modeling report. The 2000 modeling report stated that "*calibration ordinarily involves verification with a second independent data set. A second three-day data set was not collected in 1997 and for this reason the update of the model is considered incomplete. An additional three-day data set is recommended for the next year MDEP is scheduled to be in the Penobscot River watershed, which is the summer of 2001.*"

The 2001 data are used in this report to verify the model. The verification effort actually involves re-consideration of parameter rates in both data sets. The lack of a satisfactory calibration for chlorophyll-a on the West Branch locations, in particular, was considered a weakness of the original calibration effort. The addition of the periphyton module and the capability to simulate daily dissolved oxygen fluctuations in QUAL2MDEP should result in better model calibration. Many of the algae component parameters were changed in this modeling effort. The parameter rates used in the model calibration / verification are displayed in tables 6 (rates variable by model reach) and 7 (rates constant in all model reaches). The rates used for the Penobscot River were within ranges recommended in the literature.

The model calibration / verification are plotted for each chemical parameter (figures 8 to 14) in a river mile Vs chemical parameter format. The model output is displayed as a line and the data as an average (unshaded square) and range (high and low error bars). To aid the reader, a column plot (figure 6) shows the river mile of all sampling locations.

Due to the very low level of ammonia measured in the river, BOD was modeled as total ultimate BOD and not partitioned into the carbonaceous and nitrogenous fractions. A benthic CBOD source rate of 30 mg / ft^2-day was assigned to all model reaches. This value was obtained by a trial an error procedure in the modeling that resulted in UBOD values throughout the entire river in the model output that were similar to background values, after all point sources were removed.

In a large river with many impoundments where currents are not significant, the UBOD decay rates derived in the laboratory test often give satisfactory results for an estimation of the actual ambient rates. The Penobscot falls into this category river type. The laboratory rates are derived from a least square regression line fit of many UBOD values measured over the 60 day time period. The following equation is used in this analysis.

$$\mathbf{BOD_t = UBOD\ (1\text{-}e\text{-}^{kt})}$$

Where:

BOD_t = BOD in ppm at any given time
BOD = The final ultimate BOD in ppm
K = The BOD decay rate (/day)
T = Time in days.

Depending upon the data set, the UBOD decay rates varied from 0.03 to 0.05 /day. The 97 data set was assigned a rate of 0.05 /day and the 01 data set 0.04 /day in fresh waters and 0.03 /day in tidal waters. This results in a satisfactory fit of modeled to observed UBOD values (figure 7).

An examination of the data reveals that a large loss of phytoplankton occurs immediately below the Weldon dam impoundment. The majority of the loss is probably due to the die-off of algae. This may be due to the change in river environment from impounded to free flowing waters. The algae in the impoundments are not suited to thrive in the flowing environment and hence the rapid die-off. There is no direct input for an algae die-off rate in QUAL2, but this can be simulated as settling to compensate for this deficiency in the model (Some of the algae loss may actually be settling.)

There appears to be a large uptake of dissolved phosphorus from the Rockabema dam to the Weldon dam in excess of that needed for algae growth. An additional PO4-P uptake rate was assigned to three model reaches (9 to 11) here. Both QUAL2 versions have a direct input for an orthophosphorus source to the water column from the sediment, but not a direct input for uptake, or orthophosphorus loss from the water column to the sediment. Orthophosphorus uptake, this can be indirectly simulated as a negative source rate from the sediment.

When these and some other adjustments were made to the model, a good calibration of chlorophyll-a and nutrients results (figures 7 to 11).

The dissolved oxygen calibration involves both a daily average calibration and a daily minimum calibration. The former involves running the model in the steady state mode and comparing the model output to the daily average dissolved oxygen observed in both data sets. The latter involves running the model in the dynamic mode and comparing the model output to the AM and PM dissolved oxygen observed in both data sets.

In the 2000 modeling effort, periphyton and the resulting diurnal dissolved oxygen swings could not be directly modeled. To simulate the daily minimum dissolved oxygen, a diurnal adjustment was made to the model run in steady state mode. The diurnal adjustment was based the difference observed in the data between the daily average and daily minimum dissolved oxygen (Figure f2, Penobscot River Modeling Report, June 2000). Since periphyton can now be modeled, this diurnal adjustment is no longer necessary except in tidal waters. The difference in river depth and water chemistry in downstream boundary (ocean) when comparing the low and high tide data results in the necessity of a diurnal dissolved oxygen adjustment. Simulation of time variable boundaries and depth is not possible in QUAL2. The diurnal adjustment applied to tidal waters ranged from 0.10 to 0.50 ppm (Figure 12).

The calibration of dissolved oxygen involves the initial steps of calibrating BOD, chlorophyll a, and nutrient and subsequent steps of estimating the reaeration rate (K_a) and sediment oxygen demand rate (SOD) for each modeled reach of river4. K_a and SOD are typically very variable over the length of a river and the rates assigned can be quite different reach by reach. The rates assigned to the model are identical to those assigned in the 2000 modeling effort (Table 6).

There are a number of formulas to estimate reaeration based upon research by experts. Up to eight different formulations can be specified by the user in QUAL2. The O-Connor Dobbins reaeration formula which calculates reaeration as a function of velocity and depth was used in most reaches.

---

4 The reaeration rate, K_a, is the rate at which oxygen from the atmosphere enters the water column at the surface. K_a is typically high in stretches of rapids or shallow water, and low in impounded or sluggish water. Sediment oxygen demand is the oxygen demand exerted by bottom sediments to the water column.

$$k_a = 12.85\ V^{.5}/D^{1.5}$$

where v = velocity in fps, and D = depth in ft

In the deeper and lower velocity reaches, k_a was calculated by an impoundment reaeration formula which is considered a lower bound for k_a whenever the O Connor-Dobbins formula results in a lower estimate.

$$k_a = 3/D$$

This option is not directly available in QUAL2, but can be calculated outside the model and input as a user specified rate.

SOD analysis at eight river and four estuary locations was undertaken in the autumn of 2001 led by USEPA with field assistance from MDEP and the Penobscot Nation. The data report of May 2002 describes the SOD sample collection as follows: *"In most sample locations of the Penobscot, it was difficult to collect sediment samples in the main channel, due to the lack of adequate sediments. There is, no doubt, great scouring of sediments in a large river such as the Penobscot occurs during high flow periods. Sediment samples were collected in known depositional areas that were often outside the main channel."* The results of the SOD analysis resulted in high levels at many locations when compared to other river systems in Maine. The model inputs were often much lower than those reported in the analysis (Figure 13). It is deduced that the SOD in depositional areas may be much higher than the average value throughout the river bottom. The SOD measured in depositional areas is a good upper boundary of the maximum amount that can be expected on the Penobscot.

The parameter rates used for each model reach are summarized in table 6. The calibration of dissolved oxygen with these parameter rates results in a good fit of the model output to the daily average (Figure 14) and daily minimum of the measured data (Figure 15). Of all sample locations compared, 71% and 87% of average dissolved oxygen were within 0.2 and 0.3 ppm, respectively, of the observed data.

Model Predictions Runs at 10-Year Low Flow

After the water quality model is calibrated to observed data, a prediction run is made at worst case conditions to assure dissolved oxygen criteria will be achieved at all locations. Worse case conditions are defined by low river flows, when dilution of wastewater is at a minimum; by high water temperatures, when the saturation of dissolved oxygen is lower and BOD decay and oxygen demand from the sediment are higher; and by point sources discharging at licensed limits. Non- point source loads are accounted for as tributary loads with pollution concentrations as measured in the August 1997 survey, distributed load inputs in the model incremental flow, and as sediment oxygen demand (which results partially as sediment that has settled during runoff events prior to low flow).

The 7-day 10-year low flow (7Q10)[5] is used to assess compliance with dissolved oxygen criteria. Prior estimates of 7Q10 were based upon USGS gages at the period of record up to 1991. This analysis was updated to also include the years from 1992 to 2002. The updates resulted in new 7Q10's of 3070 cfs at the West Enfield gage and 3170 cfs at a discontinued USGS gage at Eddington (Figure 16). A flow balance was derived to determine various 7Q10 flows and 1Q10
flows at different locations (Table 5). Dilutions for the toxics program regulation for point source discharges (Chap. 530.5) will be changed based upon this updated information (Table 8).

Table 8 Dilution of Riverine Point Source Discharges

	Effl Flow mgd	River 7Q10 cfs	River 1Q10 cfs	Old Dilution		**New Dilution**	
				Chronic	Acute	**Chronic**	**Acute**
GNP West	43	2216	2000	30.1	7.5	**33.2**	**7.8**
Millinocket	2.33	2219	2000	556	140	**615**	**139**
GNP East	33	2226	2007	39.2	9.8	**43.5**	**10.1**
Eastern Paper	16.3	2822	2703	111	24.6	**112**	**27**
Lincoln	1.07	2822	2703	1626	349	**1703**	**408**
Old Town	1.7	2795	2521	1191	254	**1062**	**239**
GP Old Town	24.4	2802	2527	83.5	17.7	**74.1**	**17**
Orono	1.84	3178	2867	1329	283	**1115**	**252**
Veazie	.35	3183	2871	12251	2604	**5868**	**1323**
Bangor	18	3206	2892	139	30.2	**116**	**26.2**
Brewer	5.19	3243	2925	478	102	**404**	**91.2**

To determine the appropriate river temperature that should be used for the design in the model prediction runs, historical temperature data was first examined at Eddington. This data appears to indicate a trend of increasing river temperature from 1979 to 1994. It was determined that water temperatures of 25 $^{\circ}C$ and 24 $^{\circ}C$ were appropriate to use as weekly average and monthly averages values, respectively (Figure 17). Since the river temperature can vary by as much as 9 $^{\circ}C$ when comparing all sample locations on any given day, adjustments were derived for other locations based upon the 1997 and 2001 data (Figure 17). Hence the design weekly average river temperature is about 23 $^{\circ}C$ at Millinocket; increases to 25 $^{\circ}C$ in Bangor; and eventual decreases to about 15 $^{\circ}C$ at Bucksport (Figure 17). Note that the water temperatures experienced in the 2001 survey for three consecutive days are considered extreme, and would probably not occur for seven consecutive days simultaneously at a 7Q10 flow event.

5 The 7-day 10-year low flow (7Q10) is the lowest 7-day average flow expected to occur at a frequency of once in ten years. The 1-day ten year low flow (1Q10) is the lowest single day flow expected to occur at a frequency of once in ten years.

Two tests are run with the water quality model to check dissolved oxygen compliance with statutory criteria; one to test compliance of minimum dissolved oxygen criteria and a second to test compliance with the monthly average criteria of 6.5 ppm. In the first test assessing compliance with minimum dissolved oxygen criteria, river flows are inputted as 7Q10; river temperatures are inputted as a weekly average; and point sources are inputted at their weekly average licensed loads. Since the paper mill licenses have no weekly average BOD5 on their permit, ratios of weekly average to daily maximums were derived, based on three years of discharge monitoring data provided by the mill personnel. In the second test assessing compliance with monthly average dissolved oxygen criteria, river flows are inputted as 30Q10; river temperatures are inputted as a monthly average; and point sources are inputted at their monthly average licensed loads.

In both these runs, pollutants that are not included in the license such as nitrogen or phosphorus are ordinarily inputted as measured in the calibration data (August 1997 and 2001). The ultimate point source BOD must be derived from the product of a BODu/BOD5 ratio (which is derived from data) and the licensed BOD5 concentration. Point source inputs to the model and related information is summarized in tables 9 and 10.

The classification of the Penobscot River changes from B to C in the riverine portion and is classified SC in the estuarine portion of the river. Although the classification and dissolved oxygen criteria applied to each classification are discussed earlier in the text, it is repeated here for convenience sake. The following five segments define its classification:

1. From the Ferguson Lake outlet to the Mattawamkeag River – Class C
2. From the Mattawamkeag River to 1 mile above the West Enfield Dam – Class B
3. From 1 mile above the West Enfield Dam to the West Enfield Dam– Class C
4. From the West Enfield Dam to Reed Brook in Hampden – Class B
5. From Reeds Brook to Bucksport – Class SC

The dissolved oxygen criteria is as follows:

Class B Daily minimum $\geq$ 7.0 ppm and 75% of saturation
Class C Daily minimum $\geq$ 5.0 ppm and 60% of sat.; monthly average $\geq$ 6.5 ppm
Class SC Daily minimum > 70% of saturation

The model prediction run of point sources discharging licensed amounts indicates that minimum dissolved oxygen criteria should be met in class C and SC segments. However about 51 river miles are not expected to meet the minimum class B criteria (figure 18). The following locations are projected not to meet minimum dissolved oxygen criteria:

1. A forty-eight-mile class B segment (RM 61 to 13) from the Mattawamkeag River confluence in Winn to the Milford dam. The lowest dissolved oxygen level predicted is 6.3 ppm, which is within 0.7 ppm of minimum class B criteria
2. A three-mile segment (RM -3 to -6) in tidal waters from the approximate location of the Bangor and Brewer outfall pipe to the Reeds Brook confluence. The lowest dissolved oxygen level predicted here is 6.3 ppm, which is within 0.7 ppm of minimum class B criteria

In addition, algae blooms (chlorophyll a > 8 ug/l) are projected for 11 miles of the river including impoundments from Dolby dam to Weldon dam with chlorophyll a levels as high as 14 ug/l predicted. About 11 addition miles of estuarine waters are projected to have chlorophyll a levels between 8 and 9 ug/l, slightly over the bloom threshold .

The model prediction run at 30 Q10 flow to check compliance with monthly average dissolved oxygen criteria of 6.5 ppm indicates that criteria will be met everywhere except above the Rockabema dam, reaching a low of 6.4 ppm (figures 19). Since this is within 0.1 ppm or measurement error, it can be considered to be marginally complying with the monthly average criteria.

Model prediction runs with point sources at licensed conditions are compared with point sources at zero discharge levels (figure 17) and point sources at actual discharge levels (Figure 19) as indicates by summer discharge monitoring report from 1999 to 2002. It should first be pointed out that the actual discharge levels are typically much less than licensed discharge levels. For example, point sources collectively discharged about 38% of their licensed BOD5 in the summers from 1999 to 2002 (Figure 21).

The model runs indicate that dissolved oxygen criteria are met at zero discharge conditions, although only marginally at the beginning (RM 61) and end (RM –6) of the class B segment. Point sources collectively contribute up to 1.1 ppm of the dissolved oxygen depletion, which are about 56% of the total deficit from saturation. Of the remaining 44%, there may be additional dissolved oxygen depletion attributable to point sources contribution to sediment oxygen demand.

The model runs comparing licensed conditions to actual conditions indicate that the length of non-attainment is similar with actual discharge levels (47 miles) when compared to licensed discharge levels (51 miles). Dissolved oxygen levels should improve by about 0.2 ppm, and the minimum dissolved oxygen of 6.5 ppm would be 0.5 ppm within Class B minimum criteria. The model inputs for actual discharge levels are summarized in Table 11.

Table 11 Model Input for WWTP Performance Run

	Flow mgd	Flow cfs	DM Load	BOD5 ppm	CBu/B5	NBODU ppm	TBODu ppm	TBODu PPD
GNP West	20.9	32.40	8247	47.3	3.25	19	173	30115
Millinocket	0.82	1.27	177	25.9	2.06	72	125	857
GNP East	21.1	32.71	1451	8.2	2.13	6	24	4146
Eastern Pape	10.8	16.74	5070	56.3	2.23	9	135	12117
Lincoln	0.36	0.56	51	17.0	1.46	17	42	126
Old Town	0.89	1.38	403	54.3	1.63	56	144	1073
GP Old Town	15.9	24.65	3576	27.0	4.85	4	135	17874
Orono	0.72	1.12	99	16.5	1.88	4	35	210
Veazie	0.11	0.17	16	17.4	4.21	5	78	72
Bangor	5.88	9.11	907	18.5	2.91	14	68	3326
Brewer	2.48	3.84	232	11.2	2.2	2	27	552
IP Bucksport	12.9	20.00	1019	9.5	3.63	3	37	4022

Sensitivity Analysis

In a sensitivity analysis, some of the parameter rates can be tested to determine which are more important in the development of the model. The model prediction run at 7Q10 was used as a basis for the sensitivity analysis runs. Four different parameter inputs are tested; the sediment oxygen demand rate, reaeration rate, BOD decay rate, and algae (phytoplankton and periphyton) growth rates. Each parameter was multiplied by a factor of 0.5 and 2 and the model output for dissolved oxygen was then compared as a range at three strategic locations (figure 22). The three locations chosen are above the Rockabema dam, a point midway between the Greenbush and Passadumkeag sampling locations, and at Orrington at the end of the class B segment. It is at these locations that the lowest dissolved oxygen readings are predicted and hence the most sensitivity is expected.

From this analysis it appears that the order of sensitivity in the calibration of the model dissolved oxygen are the atmospheric reaeration rate, followed by the sediment oxygen demand rate, the BOD decay rate, and finally the algae growth rate. The reaeration rate and sediment oxygen demand rate appears to be sensitive at all locations. The algae growth rate appears to be more sensitive in shallower flowing segments (Greenbush-Passadumkeag). The BOD decay rate appears to be more sensitive in the deeper reaches (Rockabema dam and Orrington).

Component Analysis

Components of potential river dissolved oxygen depletion are compared in two ways. First pollutant loads inputs to the Penobscot River as a whole can be computed and compared in pie chart diagrams. The larger loads have more potential for impact.

Second, the actual impact each load has to the river dissolved oxygen depletion can be determined with model prediction runs. In this analysis, load inputs are individually subtracted from the model and the difference in dissolved oxygen predicted by the model from a base case is then observed. The model prediction run at 7Q10 flow and licensed point source loads was used as a base case for the component analysis.

Point source, tributary, and background input loads are compared as pie chart diagrams for total ultimate BOD and total phosphorus (figure 23). The tributary and background loads are computed using pollutant concentrations as measured during the intensive surveys and represent both natural and non-point source pollutant loads. From this analysis it can be observed that point source inputs when discharging at maximum licensed conditions are overwhelmingly the largest source of pollution representing about 74% and 94% of the total input of BOD and phosphorus, respectively.

Point source input loads are compared for BOD5 (Figure 24) and total phosphorus (Figure 25). From this analysis, it can be observed that paper mills collectively are the largest pollutant source that accounts for more than 80% and 70% of the BOD5 and total phosphorus, respectively of all point source discharges. The city of Bangor accounts for about 11% and 18% of the total BOD5 and phosphorus, respectively. Other municipal sources (Millinocket, Lincoln, Old Town, Orono, Veazie, and Brewer) individually seem insignificant, since each discharges is typically less than 3% of the total point source loads. However, when considered collectively, they are significant representing about 8% and 10% of the total point source inputs for BOD and phosphorus, respectively.

The component analysis of the dissolved oxygen deficit is analyzed at the same three strategic locations as the sensitivity analysis; above the Rockabema dam, Passadumkeag – Greenbush midpoint, and Orrington at end of class B segment. Five components of dissolved oxygen depletion were investigated:

1. Sediment oxygen Demand (SOD) – Includes all SOD collectively from natural, point source, and non-point sources.
2. Point Source BOD – Includes nitrogenous and carbonaceous BOD from all industrial and municipal sources.
3. Non-point Source BOD - Includes nitrogenous and carbonaceous BOD from tributary and incremental drainage. Includes both natural and non-point source pollution.
4. Background – Model run with no background impact. Dissolved oxygen is adjusted to 100% saturation and background BOD is adjusted to zero. Collectively includes impacts from the initial DO deficit and background BOD from natural and non-point sources.
5. Point Source Nutrients – Diurnal dissolved oxygen impacts from attached and floating algae. Includes nutrient impacts from point sources.

Above the Rockabema dam (Figure 26), sediment oxygen demand and background conditions are the largest factors contributing to dissolved oxygen depletion resulting in about 37% each of the total dissolved oxygen deficit. Point source BOD is responsible for about 18% of the total dissolved oxygen depletion. Point source nutrients and non-point source BOD are less important, contributing about 7% and 1%, respectively to the total dissolved oxygen deficit. At the Passadumkeag – Greenbush midpoint (Figure 26), point source nutrients and sediment oxygen demand are the largest factors contributing to dissolved oxygen depletion resulting in about 45% and 35% of the total dissolved oxygen deficit, respectively. Point source BOD contributes about 11%; background conditions about 5%; and non-point BOD about 4% of the total dissolved oxygen deficit.

At Orrington (Figure 26), point source BOD and sediment oxygen demand and are the largest factors contributing to dissolved oxygen depletion resulting in about 43% and 37% of the total dissolved oxygen deficit, respectively. Non-point source BOD and background conditions are responsible for about 13% and 7%, respectively, of the total dissolved oxygen deficit. Nutrients are unimportant resulting in less than 1% of the total dissolved oxygen depletion.

Investigation of Pollutant Abatement

Model prediction runs with point sources at both licensed and actual conditions resulted in widespread non-attainment (up to ½ of the 103 river miles investigated) of minimum class B dissolved oxygen criteria. In addition, the model predicts that algae blooms should occur in up to ¼ of the length of the 103 miles investigated. Point sources are the main cause of the dissolved oxygen depletion and the algae blooms. Clearly reductions of point source inputs are necessary for attaining compliance of dissolved oxygen criteria.

Additional model runs are made with point source reductions of BOD and phosphorus. Phosphorus is the limiting nutrient responsible for the growth of benthic algae and phytoplankton (floating algae). Limiting phosphorus inputs to the river will limit algae production, which will also alleviate the early morning low dissolved oxygen readings that result from extended evening respiration. The algae typically produce excess oxygen when exposed to light during the daytime through photosynthesis, and the maximum daily dissolved oxygen is reached at mid to late afternoon. Conversely, at night in the absence of light, extended respiration results in a continuing depletion of dissolved oxygen until minimum daily values are achieved at dawn.

The point source reductions can be accomplished in a number of methods. One method could be requiring the larger point sources to undertake most of the reductions, since they are responsible for most of the impact. Another method could be requiring all point source inputs to do some abatement with the larger inputs doing more abatement than the smaller inputs. **In summary, it has been determined that if point source discharges are reduced to levels slightly higher**

than actual BOD input levels6 (about a 60% collective reduction from licensed amounts), and point source total phosphorus reduced by about 40% from actual levels, all criteria could be marginally attained.

A summary of model run inputs and prediction results (table 12) and point source load inputs for each model run (table 13) illustrate the expected water quality for the various load reductions investigated. Model runs are also plotted in a river mile Vs dissolved oxygen level format (Figure 27). Phosphorus for point source discharges is typically regulated as a monthly average discharge in the summer months (May 15 to Sept 30). BOD5 is regulated in the summer months as a monthly and weekly average or possibly a daily maximum.

Table 13 Summary of Point Source Loads (PPD) in Model Prediction Runs at 7Q10 Flow

	Pen.7qt		PenP.7qt		PenP2.7qt		PenP3.7qt		PenP4.7qt		PenP6.7qt	
	TP	BOD5 WA*	TP	BOD5 DM**	TP	BOD5	TP	BOD5	TP	BOD5	TP	BOD5
GNP West	502	13680	244	8247	87	8247	87	8247	87	8247	87	8715
Millinocket	80	874	28	177	28	177	80	874	28	874	28	205
GNP East	385	6710	246	1451	88	1451	88	1451	88	1451	88	1760
Eastern Pap	114	8191	76	5070	45	5070	45	5070	45	5070	45	2702
Lincoln	35	402	12	51	12	51	35	402	12	402	12	90
Old Town	69	638	36	403	36	403	69	638	36	638	36	223
GP Old Town	244	12780	159	3576	66	3576	66	3576	66	3576	66	3978
Orono	47	690	18	99	18	99	47	690	18	690	18	180
Veazie	11	131	3	16	3	16	11	131	3	131	3	28
Bangor	650	6755	212	907	212	907	650	6755	212	907	212	1471
Brewer	31	1947	15	232	15	232	31	1947	15	1947	15	620
Totals	**2168**	**52799**	**1050**	**20229**	**611**	**20229**	**1209**	**29781**	**611**	**23933**	**611**	**19973**

* Weekly Average Loads. For paper mills, derived by daily maximum load times WA/DM ratio from discharge monitoring reports.

** Daily maximum load used for performance runs.

It should first be mentioned that the discharges in Winterport and Bucksport are well below the impacted river and estuary segments. Even though some portion of their effluent discharge may reach the impacted segments during an incoming (flood) tide, model runs assessing their impact determined that their inputs collectively is negligible. Hence no point source controls other than

6 For model runs at performance or actual levels, the average of the daily maximum pollutant load inputs for each summer month from 1999 to 2002 were used to simulate weekly average loads at 7Q10 flow (no weekly average load input data was available). The daily maximum load set for point sources would be slightly higher than the inputs used in the model which are a weekly average.

those that currently exist within licenses are recommended for Bucksport, Winterport, and the International Paper mill in Bucksport. The dilution and dispersion of the Penobscot estuary in the location of the outfalls of these discharges is very large and adds insurance that regulation of these discharges will do little to improve the non-attainment areas. Also, the estuary becomes nitrogen limited rather than phosphorus limited in Winterport and Bucksport. If nutrient controls were implemented here, nitrogen reductions, rather than phosphorus reductions would be implemented.

It would appear that the most equitable way of achieving the phosphorus reductions would be restricting paper mill discharges to mass loads calculated by actual flow and phosphorus treated to a 0.5 ppm level. Municipal discharges should be capped at current phosphorus input levels based upon actual flow and phosphorus as measured in the 97 and 01 surveys. The required monthly average phosphorus loads for each discharge under this case are summarized in Table 13, run PenP6.7qt (2^{nd} column from far right).

No phosphorus requirements were also investigated for municipal point sources (model run PenP3.7qt) along with the mentioned paper mill reductions, but it was determine that this would not be enough, since 26 river miles would still not attain dissolved oxygen criteria and 10 river miles still experience algae blooms. Additional phosphorus reductions from mill discharges would be necessary without regulating municipal discharges. A 0.5 ppm TP level may be achievable at each paper mill by undertaking process controls, i.e. optimizing phosphorus addition, and levels lower than 0.5 ppm could require large capital investments.7

For the BOD reductions many methods are possible. One possible method is holding all point source discharges to performance based standards (model run PenP2.7qt). This may not be the most equitable method, since dischargers who are performing well will be regulated at much lower levels than discharges who are performing poorly (hence good operation of a plant is penalized). Another method that appears to be more equitable is requiring BOD5 loads based upon an equal concentration and actual treatment plant flow. A BOD5 concentration of 30 ppm would be required as a weekly average to meet the necessary load reductions. The loads for this method for each point source are summarized in table 13, model run PenP6.7qt (in the column to the far right).

For the phosphorus reductions, two allocation methods are presented for municipal discharges. The first involves capping all municipal discharges at their current mass load. A more equitable method analogous to the BOD allocation method may be calculating required TP loads based

---

7 Paper mill effluent is typically nutrient deficient and phosphorus is added to the treatment process to optimize BOD removal. Often much more phosphorus is added than what is needed (see GNP study appendix). Studies should be undertaken at each paper mill to determine the minimum amount of phosphorus that needs to be added while still insuring good BOD removal. In some paper mills, studies have determined that no nutrient addition is actually needed.

upon an equal concentration. The concentration that would be required at actual flow using this method is 3.45 ppm.

Actual treatment plant BOD5 performance data for the years 1999 – 2002 are plotted and compared to current licensed levels and allocation based upon the 30 ppm BOD5 allocation (Figure 28a, 28b, 28c). Note that the daily maximum allocation is adjusted to reflect a daily maximum rather than the weekly average inferred in the model run. The ratio used for this adjustment are the inverse of those appearing in table 9 (weekly/daily maximum BOD ratio). It appears that Eastern Paper and Old Town would have the most difficulty meeting this allocation. Old Town is currently undertaking a plant upgrade, which could result in significant improvements in performance.

Another possibility, which should be mentioned, is a water quality trading system. Hence a discharge that could have difficulty meeting a required phosphorus or BOD level could possibly trade pollutant credits with another discharge who is expected to be well under future requirements. Note that in the model runs provided, GNP west and GNP east have already been modeled assuming pollutant trading that is more consistent with how the plants actually perform (West is based upon BOD5 = 50 ppm; East BOD5 = 10 ppm). Note that in a pollutant trading system, pollutants are not necessarily traded in a 1:1 ratio, since where each input is located in relation to impacted river areas must also be considered. Finally it should be stated that DEP is open to other allocation methods, so long as the desired goal of attainment of water quality standards is achieved. The following allocations are offered for starting points of discussion.

Table 14 Point Source BOD5 and Phosphorus Allocation Municipal Discharges

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by current discharge	Allocate by equal concentration
Millinocket	180 / 200	210 / 230	28	24
Lincoln	50 / 55	90 / 100	12	10
Old Town	400 / 480	220 / 250	36	26
Orono	100 / 110	180 / 200	18	21
Veazie	16 / 18	28 / 31	3	3
Bangor	900 / 1000	1470 / 1630	212	169
Brewer	230 / 250	620 / 690	15	71
Winterport	Primary Plant		No Restriction	
Bucksport	Primary Plant		No Restriction	

Paper Mills

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by equal % Reduction	Allocate by equal concentration
GNP West	8200 / 10800	8700 / 11500	96	87
GNP East	1450 / 2600	1800 / 3200	97	88
E Paper Lincoln	5000 / 6800	2700 / 3700	30	45
G Pacif Old Town	3600 / 5100	4000 / 5600	63	66
IPCo Bucksport	7100 / 10000*	No Restriction		

* Current licensed level