NOTE:

1. Professional judgment should be applied in assessing the appropriateness of the quality assurance elements which follow. In specific situations, it may be necessary to add, modify or delete items found in the template. These actions should be documented, accompanied by an explanation and identified in the companion checklist.
2. This template is for model development, evaluation and application and for models used for comparative purposes (Appendix C).
3. Additional guidance on model development, evaluation and application may be found in the references and, in particular, the EPA document (U.S. EPA. 2009) *Guidance on the Development, Evaluation and Applicability of Regulatory Environmental Models* found at the following internet address: http://www.epa.gov/crem/library/cred_guidance_0309.pdf

Template for Developing a Generic (or project-specific) Quality Assurance Project Plan (or plan elements) For Model Development, Modification, Evaluation and Application

Project Name
Affiliated Program & Associated Contract or Assistance Agreement Number

Prepared by
Name and Address

Prepared for
Regional EPA Office and Address

Provide the project title, name of organization conducting the project, and personnel with approval authority. Approval authorities typically include project organization and regulating authorities such as EPA.

Approvals Signature (required prior to project start):

_____ _____Date:
Project Manager Print Name

_____ _____Date:
QA Officer Print Name

_____ _____Date:
EPA Project Manager/Officer Print Name

_____ _____Date:
EPA QA Manager/Representative Print Name

Table of Contents

NOTE: List the section/subsections of the document and all figures, tables, and appendices. Provide associated section/subsection numbers and pages so that all information may be readily found in the document.

1.0 PROJECT MANAGEMENT

1.1 Title and Approval Page (EPA QA/R-5 A1) - See page 1.
http://www.epa.gov/quality/qs-docs/r5-final.pdf

1.2 Table of Contents (EPA QA/R-5 A2) - See pages 2 - 4.

1.3 Distribution List (EPA QA/R-5 A3 *see also EPA NE Website Streamlined Tables)*
http://www.epa.gov/NE/lab/qa/streamlinedqapp.html

List all the individuals (along with their titles, organizations, and contact information) who will receive original copies of the approved Quality Assurance Project Plan (QAPP) and any subsequent revisions. Include all persons who are responsible for project implementation (including project managers, QA managers, and representatives of all groups/agencies involved).

Below is an example outline of how you may present the information for this section. Please revise/edit the information, as appropriate, for your project team.

Name:
Title:
Organization:
Contact Information (Address, Telephone, E-mail, etc.):

Name:
Title:
Organization:
Contact Information (Address, Telephone, E-mail, etc.):

Etc.

1.4 Project Organization (EPA QA/R-5 A4)

Identify the individuals and organizations participating in the project, and discuss their specific roles and responsibilities. Include program or project management, personnel responsible for conducting project activities, the project QA manager, and points of contact and associated organizations for all consultants and/or contractors. If associated names and contact information are not identified elsewhere, provide them here. Whenever possible (depending on the size of the organization), ensure that the project QA manager is independent of the staff generating the data and model outputs.

Provide a concise organization chart showing the relationships and lines of authority/ communication for all named people and organizations. Identify who is advisory only.

Below is some example language to consider including. Please ensure the name of the individual associated with each title is presented.

Project Manager will be the responsible official for overseeing the overall projects and budgets, as well as tasking contractors with work required to complete projects. He/she will communicate project needs to the contractor's project manager.

QA Manager or Designee will be responsible for reviewing and approving and maintaining the QA Project Plan. He/she may provide technical input.

Contractor (or Grantee) Project Manager will have overall responsibility for assigning appropriate personnel to complete the tasks included in this plan. He/she will ensure that the project budget is adhered to. He/she will communicate with the Project Manager on work accomplished in this plan and any problems or deviations that need to be resolved.

Other Key Project Positions -

1.5 Problem Definition/Background (EPA QA/R-5 A5 at http://www.epa.gov/quality/qs-docs/r5-final.pdf and also EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

State the specific environmental problem(s) to be investigated. Include sufficient background information to provide an historical and scientific perspective for future projects.

State decisions to be made, actions to be taken, or outcome expected from the information obtained from modeling activities.

Identify the regulatory information, applicable criteria, action limits, etc. that the model outcomes will reference.

Identify assumptions for the modeling process.

Provide for notification when new models will be created that will justify the inability to use existing models in certain situations.

Provide for notification of modifications to model code.

Describe how the suitability of models to resolve the application niche will be evaluated by:

- *Mapping model attributes to problem statements*
- *Degree of certainty needed in model outputs*
- *Amount of reliable data, available resources and technical expertise*

1.6 Project/Task Description and Schedule (EPA QA/R-5 A6 at http://www.epa.gov/quality/qs-docs/r5-final.pdf)

Provide a summary of the work to be undertaken in accordance with the remaining sections of this QAPP and the schedule or timing for implementation. Include a general overview of the various pertinent work activities (such as: work to be performed in model creation or application, measurements/analyses, data evaluation, etc.), products/reports to be generated, and a targeted schedule or estimated timing for each critical activity/report. Discuss resource and time constraints, if applicable.

Provide for identification of geographical locations to be studied, including maps where possible.

1.7 Quality Objectives and Criteria for Measurement Data and Models (EPA QA/R-5 A7 see also EPA QA/G-5 and EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Describe the general objectives of the project(s) covered under the QAPP. Define how the model performance criteria and data quality acceptance criteria will be determined (for all information to be collected including information obtained from previous studies). Explain how the data acceptance criteria relate to the desired quality of model outputs.

1.7.1 Objectives and Project Decisions

Include statement(s) of the general objectives and demonstrate knowledge of the overarching purpose for the project. Phrase decisions in terms of "…if…then…" type of statements.

1.7.2 New Data Measurement Performance Criteria/Existing Data Acceptance Criteria

Describe the data quality needed to support project decisions. Discuss the data quality indicators (DQIs) and the acceptance criteria/measurement performance criteria for each DQI, and identify the quality control (QC) or other mechanism to be used to assess if the criteria were met.

Identify how acceptance/performance criteria will be established for:
Existing data (including when data is deemed outdated or otherwise excluded)
Model parameterization (calibration)
Model corroboration (validation)
Model sensitivity analysis
Model uncertainty analysis

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

1.8 Special Training Requirements/Certification (EPA QA/R-5 A8 at http://www.epa.gov/quality/qs-docs/r5-final.pdf see also EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Identify and describe any specialized training or certification requirements. Discuss how such training will be provided, as well as how and where the training records will be documented.

State that the QA Officer is responsible for overseeing training.

Indicate the personnel responsible for assuring that these tasks are satisfied.

1.9 Documents and Records (EPA QA/R-5 A9 see also Example Tables, *EPA NE Website Streamlined Tables)* *http://www.epa.gov/NE/lab/qa/streamlinedqapp.html*) and see also EPA QA/G-5M

Summarize the type of information necessary to be included in report packages, including electronic data deliverables.

Describe the format for reporting of model development/modification, evaluation and application and for model inputs and model outputs.

Identify any other project records to be maintained, how/where the records will be stored, and the length of time of storage. This should include information generated in assessment/oversight reports, interim progress/status reports and final reports, including:

Technical reviews, model tests, data quality assessments of output data and results;
Candidate model assessments for model selection, including references;
Actual input used and data bases used;
Pre- and post-software development information;
Spreadsheet data files containing monitoring data; and
Copy of modeling reports

Describe the type of information to be included in the final reports (for example: perhaps it will be summarized in a data base and/or Excel spreadsheet with all supporting information to be retained in a project file). Discuss back up plans for records stored electronically.

1.9.1 QA Project Plan Distribution

Describe the process and responsible individual for distributing the most current approved QAPP, as well as any revisions/updates, to appropriate project staff (see Section 1.4).

2.0 DATA GENERATION AND ACQUISITION

2.1 Data Acquisition Requirements (Non-Direct Measurements) (EPA QA/R-5 B9 at http://www.epa.gov/quality/qs-docs/r5-final.pdf see also EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Identify the range of data sources, for example, computer databases or literature files, and/or models that may be accessed and used. Describe the intended use of this information and the rationale for their selection, i.e., its relevance to the QAPP objectives.

Identify how acceptance criteria will be established for all previously collected information. Discuss precision, bias, representativeness, completeness and how it will be assessed in relation to model performance criteria.

Identify any types of data needed (for project implementation or decision making) that may be obtained from non-direct measurement sources such as existing data from another project, photographs and maps, literature files, and historical databases.

Discuss procedures to ensure that data used are not outdated and that there is consistency when excluding data and in documentation of excluded data.

Identify key resources/support facilities needed.

2.2 Data Management (EPA QA/R-5 B10 at http://www.epa.gov/quality/qs-docs/r5-final.pdf see also EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Describe how the data will be managed, tracing the path of data generation in the field or laboratory to final use or storage.

Describe or reference the standard record-keeping procedures, and discuss the approach to be used for data storage and retrieval of electronic media.

Discuss the plan for detecting and correcting errors from conversion of data (e.g. metric/English, units-to-units, significant figures, etc.) as well as for preventing loss of data during reduction, reporting, and entry to forms, reports, and databases.

Identify and describe all data handling equipment and procedures to process, compile, analyze and interpret the model data, including any necessary computer hardware and software. Address any specific data management performance requirements and describe the procedures that will be followed to demonstrate acceptability of the necessary hardware/software configuration.

Identify who is responsible for each data management task.

3.0 ASSESSMENT AND OVERSIGHT

3.1 Assessments/Oversight and Response Actions (EPA QA/R-5 C1 at http://www.epa.gov/quality/qs-docs/r5-final.pdf see also EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Describe the assessments to be performed "during" the project(s) to ensure activities are being conducted as planned. State the frequency and purpose of each assessment, along with the success/acceptance criteria for each assessment proposed. List the approximate schedule or timing of activities, and identify potential organizations and participants.

Define the scope of authority of the assessors, including stop work orders. Discuss how response actions to non-conforming conditions shall be addressed and by whom. Define the conditions under which the assessors are authorized to act.

Describe how and to whom the results of the assessments shall be reported. Indicate that a summary of the assessments will be provided in the modeling report and kept in a modeling journal.

Provide examples of any forms or checklists to be used to document assessments and response/corrective action activities.

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

4.0 MODEL DEVELOPMENT OR MODIFICATION

4.1 Applicability

For mechanistic modeling of common environmental problems, one or more suitable model frameworks may exist. Many existing model frameworks in the public domain can be used in environmental assessments. ***When this is the case, the requirements in this section do not apply to QA plans.***

Sometimes no model frameworks are appropriate to the task, and it is necessary to develop a new model framework or to modify an existing framework to include the additional capabilities needed to address the project needs. ***When this is the case, the requirements of this section apply to QA plans.***

The objective is to develop the conceptual model that reflects the underlying science of the processes being modeled, and develop the mathematical representation of that science and encode these mathematical expressions in a computer program.

Model development can also be viewed as a process with three main steps: (a) specify the

environmental problem (or set of issues) the model is intended to address and develop the conceptual model, (b) develop the model framework (develop the mathematical model), and (c) evaluate the model to develop the application tool (EPA 2009).

4.2 Project Plan Requirements for Model Development or Modification

Model development or modification should always be conducted using a graded approach that is adequate and appropriate to the decision at hand. Issues such as the infeasibility or non-applicability of any of these elements should be documented in the plan. The QA plan shall include, but not be limited to, consideration and development of the detailed specifications for model development identified below.

Development and intended application of the software product;

Specification of the scientific theories that form the basis for model(s);

Software to be used in its development;

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

Functional requirements of the software product;

Most important functions that the software product must address;

Computer hardware and operating system requirements for the software product;

Any quantitative or qualitative quality objectives for the software product;

Evaluation of each component model, as well as the full system of integrated models, where applicable;

Documentation for the selected model clearly stating why and how the model can and will be used;

Quality objectives for uncertainty analysis either qualitatively or quantitatively (See EPA 2009);

4.2.1 Evaluation of the Model Framework

The QA Plan shall indicate that the following will be evaluated and documented during model development or modification;

Soundness of the science (including peer-reviewed theory and equations) underlying hypothesis;

Appropriateness of model complexity for the problem at hand;

Data quality and quantity objectives to support the choice of model;

Consistency of model structure with all the relevant inputs described in the conceptual model;

Identification of the model code and code verification, if completed;

Implementation process for the software product and any applicable development standards;

Internal quality checks applied during the development process (e.g., design and code verification, configuration control procedures, and change control procedures);

Procedures for controlling, documenting, and archiving, all significant changes to the software and hardware;

Testing strategies including individual module tests, integration tests, systems testing, acceptance testing, and beta testing, as applicable. The procedure for each test shall be provided and the process of confirming the test results included. That is, evaluation criteria are to be identified during the initial stages of model development;

Requirements for project documentation (e.g., design document, source code, and user guide); and

Expected maintenance and user support needed by the software product.

It is also recommended that the evaluation process apply the principles of scientific hypothesis testing (Platt 1964) using an iterative approach (Hilborn and Mangel 1997). When evaluating multiple model frameworks, it may be useful to statistically compare the performance of these competing models with observational, field, or laboratory data (EPA 2009).

See also Appendix A.

5.0 LIFECYCLE MODEL EVALUATION

Model evaluation in this template means to test that the model expressions have been encoded correctly into the computer program and test the model outputs by comparing them with empirical data. Model evaluation is an iterative process. Hence, it may be effectively applied throughout model development, testing, and application and should not be interpreted as the sequential step "model evaluation."

Model evaluation is the process for generating information over the life cycle of the project that helps determine whether a model and its analytical results are of sufficient quality to serve as the basis for a decision. Model quality is an attribute that is meaningful only within the context of a specific model application. In simple terms, model evaluation in the QA plan shall provide information to help answer the following questions:

- *How have the principles of sound science been addressed during model development?*
- *How is the choice of model supported by the quantity and quality of available data?*
- *How closely does the model approximate the real system of interest?*
- *How well does the model perform the specified task while meeting the objectives set by quality assurance project planning? (EPA 2009)*

5.1 Project Plan Requirements for Lifecycle Model Evaluation

Model evaluation should always be conducted using a graded approach that is adequate and appropriate to the decision at hand. Issues such as the infeasibility or non-applicability of any of these elements should be documented in the plan. The plan shall include, but not be limited to, the questions above and consideration and development of the detailed specifications for model evaluation identified below:

Identification of the mathematical algorithms and approaches to be used in executing the model computations;

Appropriateness of input data (specify the availability and quality of monitoring and laboratory data to be used for both developing model input parameters and assessing model results);

Appropriateness of boundary condition specifications;

Assumptions and limitations and affect on model applicability, if any;

Applicability and appropriateness of selected parameter values;

Documentation and justification for adjusting model inputs to improve model performance (calibration, where applicable);

Model application with respect to the range of its validity;

Quality assurance and quality control (QA/QC) activities involving planning, implementation, documentation, assessment, reporting, and improvement to ensure that a model and its components are of the type needed for its task and that they will meet all required performance standards; and

Requirements for documenting the model evaluation that allows individuals and groups outside modeling activities to comprehend either the processes followed in evaluation or the essential workings of the model and its outputs.

See also Appendix B.

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

6.0 MODEL APPLICATION

6.1 Model Parameterization (Calibration) (QA/G-5M) http://www.epa.gov/quality/qs-docs/g5m-final.pdf) and http://www.epa.gov/ord/crem/library/CREM%20Guidance%20Draft%2012_03.pdf

Describe the range of calibration performance measures that will be applied.

Identify the critical activities and qualitative and quantitative methods for model calibration. A few example calibration activities might be processing calibration data, decoupled calibration and sub-area calibration. A few examples of calibration methods are graphical, deviance, mean error, mean square error, automatic optimization, pure random search, multi-start and clustering methods, etc.

Describe how one or more criteria will be established to determine when to stop model parameterization (calibration).

Describe activities and methods for parameter estimation and criteria for defaulting to non site-specific data.

Describe how parameters used for calibration will be selected and how parameters to be kept constant shall be determined. Describe how parameters considered statistically important to the prediction process (and included as model inputs) will be determined.

Describe how the calibration uncertainty and soundness of calibration will be determined and how they will be related to calibration performance measures.

Discuss the activities and methods (e.g., Morris's One-at-a-Time, differential analyses, Monte Carlo analyses and variance-based methods, etc.) that will be used for conducting sensitivity analyses.

Identify how records of model parameterization (calibration) and corroboration (validation) will be maintained.

Identify how deficiencies should be resolved and documented.

6.2 Model Corroboration (Validation and Simulation) (EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf) and http://www.epa.gov/ord/crem/library/CREM%20Guidance%20Draft%2012_03.pdf

Describe the activities and (qualitative and quantitative (statistical) methods to be used for model corroboration (validation) as well as for documenting the process. A few examples of validation activities might include setting up test schemes and performance criteria to focus the simulations, processing validation data and performing validation tests. A few examples of validation methods might include graphical methods, deviance methods and statistical tests for bias and precision.

Describe how model corroboration (validation) performance measures will be established.

Describe how the soundness of validation (for example, professional judgment) and validation uncertainty will be evaluated (for example, error propagation, regression techniques and Monte Carlo simulation.)

Describe how the soundness of model simulations (for example, internal quality assurance, peer review and practical experience based evaluations) and simulation uncertainty will be determined.

Describe the use of independent data sets for model parameterization and corroboration. Discuss how issues shall be resolved and identify the authorities for resolving such issues.

Provide examples of any forms or checklists to be used in an appendix/attachment. All associated criteria identified in the documentation should be consistent with and/or supportive of the model quality objectives and performance criteria.

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

6.3 Reconciliation with User Requirements (EPA QA/R-5 D3 at http://www.epa.gov/quality/qs-docs/r5-final.pdf **and** see also EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Describe how the results (which have already been reviewed, verified, and validated/evaluated) obtained from the project will be reconciled with the project objectives and performance criteria/acceptance criteria.

Outline the proposed methods to analyze the modeling results and for determining possible anomalies or limitations on the use for the intended purpose and how departures from assumptions established in the planning phase of the modeling process will be assessed.

Describe how anomalies will be resolved, and discuss how limitations on the use of the data from anomalies and departure from assumptions will be reported to decision makers.

7.0 REPORTS TO MANAGEMENT (EPA QA/R-5 C2 and EPA QA/G-5M see also EPA NE Website Streamlined Tables at: *http://www.epa.gov/NE/lab/qa/streamlinedqapp.html*)

Identify the frequency and distribution of reports issued to inform management of the status of the project, results of performance evaluations and systems assessments, results of data quality and modeling evaluations, and any significant quality assurance problems and recommended solutions.

Indicate that the reports will address the elements in Section 7.1 below.

Identify the preparer and the recipients of the reports, and any specific actions management is expected to take as a result of the reports.

7.1 Reports (EPA QA/R-5 C2 at http://www.epa.gov/quality/qs-docs/r5-final.pdf and EPA QA/G-5M at http://www.epa.gov/quality/qs-docs/g5m-final.pdf)

Describe the content of the report(s) as including each of the following from sections 7.1.1 through 7.1.4 below.

7.1.1 Model Development or Modification

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

Specification of environmental problem;

Description of mathematical model;

Software performance against any quantitative or qualitative objectives;

Assessment of each model component and integrated models, where applicable;

Assessment of why and how the model can be used; and

Performance against objectives for uncertainty analysis.

7.1.2 Evaluation of Newly Developed or Modified Existing Model

Describe the evaluation of the model framework including;

Soundness of the science (including peer-reviewed theory and equations) underlying hypothesis;

Appropriateness of model complexity for the problem at hand;

Data quality and quantity objectives to support the choice of model;

Consistency of model structure with all the relevant inputs described in the conceptual model;

Identification of the model code and code verification, if completed;

Implementation process for the software product and any applicable development standards;

Internal quality checks applied during the development process (e.g., design and code verification, configuration control procedures, and change control procedures);

Procedures for controlling, documenting, and archiving, all significant changes to the software and hardware;

Testing strategies including individual module tests, integration tests, systems testing, acceptance testing, and beta testing, as applicable. The procedure for each test shall be provided and the process of confirming the test results included. That is, evaluation criteria are to be identified during the initial stages of model development;

Design document, source code, and user guide); and

Expected maintenance and user support needed by the software product.

7.1.3 Model Application

Introduction and Background

Purpose of Modeling/Modeling Objectives

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 Data Acceptance Criteria
References to Monitoring Data
Discussion on Excluded Data and Basis for Exclusion

Description of Model(s) (including):

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

Model Parameterization (Calibration) and Corroboration (Validation)

- *Objectives, Activities and Methods*
- *Parameter Values and Sources*
- *Rational for Parameter Values Estimated in the Absence of Data*
- *Calibration Variables and Targets*
- *Measures of Calibration Performance*
- *Calibration Input, Output and Results Analysis*
- *Model Validation Results*

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 Calibration, Validation and Simulations*
- *Review of Initial Assumptions and Model Suitability Evaluation*

Performance Against the Performance Criteria Including:

- *Model Parameterization (Calibration) and Corroboration (Validation)*
- *Model Sensitivity and Uncertainty Analyses*

Pre- and Post-Processing Software Development

Maps, Photographs and Drawings (if appropriate)

Deviations from the QAPP Including a List of Non-Applicable Reporting Elements with Explanations

Conclusions, Recommendations, References and Appendices

7.1.4 Lifecycle Model Evaluation

The QA plan should specify that in periodic reports to management and in final reports the following will be addressed:

How have the principles of sound science been addressed during model development?
How is the choice of model supported by the quantity and quality of available data?
How closely does the model approximate the real system of interest?
How well does the model perform the specified task while meeting the objectives set by quality assurance project planning?

The report shall also include the following:

Identification of the mathematical algorithms and approaches used in executing the model computations;

Appropriateness of input data (specify the availability and quality of monitoring and laboratory data used for both developing model input parameters and assessing model results);

Appropriateness of boundary condition specifications;

Assumptions and limitations and affect on model applicability, if any;

Applicability and appropriateness of selected parameter values;

Documentation and justification for adjusting model inputs to improve model performance (calibration, where applicable);

Model application with respect to the range of its validity;

Quality assurance and quality control (QA/QC) activities involving planning, implementation, documentation, assessment, reporting, and improvement to ensure that a model and its components are of the type needed for its task and that they will meet all required performance standards; and

Documentation that allows individuals and groups outside modeling activities to comprehend either the processes followed in evaluation or the essential workings of the model and its outputs.

Professional judgment should be applied. In specific situations, it may be necessary to add, modify or delete items found in the template. An explanation should be provided.

8.0 REFERENCES (and recommended references *)

Note: The following references were consulted in developing the preceding QAPP template and companion checklist.

Bay-Delta Modeling Forum and Ad hoc Modeling Protocols Committee (2001) - Protocols for Water and Environmental Modeling. January. http://www.cwemf.org/Pubs/Protocols2000-01.pdf

California EPA. 2004. Guidelines for Submittal of Information Developed from Models to the Central Valley Regional Board - State Water Resources Control Board -Water Quality. August. http://www.waterboards.ca.gov/centralvalley/plans_policies/guidance/modeling.pdf

California EPA. 2004. State Water Resources Control Board – Water Quality-Surface Water Ambient Monitoring Program (SWAMP). Electronic QAPP Template Version 1.0. March. (see above link)

Depinto, Dilks (et al.) 2002. Guiding Principles for Modeling in the TMDL Process-Limno-Tech Inc. Water Environment Federation-National TMDL Specialty Conference. http://ice.ingenta-ddconv.nsatc.net/content/wef/wefproc/2002/00002002/00000008/art00002

Dilks (et al.) 2004. Improved Consideration of the Margin of Safety in TMDL Development *in Journal of Environmental Engineering*, Vol. 130 Issue 6 pp 690-694. http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=JOEEDU000130000006000690000001&idtype=cvips&gifs=yes

Dutch Department of Public Works – Good Modelling Practice Handbook http://harmoniqua.wau.nl/public/Reports/Existing%20Guidelines/GMP111.pdf

***European Commission (2005) -** Harmonising Quality Assurance (HarmoniQuA) in model based catchment and river basin management. http://harmoniqua.wau.nl/

European Commission – Harmoni-CA Guidance on Uncertainty Analysis (see "Work package 2 Public – Guidance 1 Uncertainty Analysis.pdf") http://www.harmoni-ca.info/About_Harmoni-CA/Work_Packages/Work_Package_2/index.php

European Commission – Data Uncertainty Engine (DUE) Manual http://harmonirib.geus.info/xpdf/d2-4_due_manual_v3.0_final.pdf

European Commission – HarmoniRiB Uncertainty Software for Data Uncertainty Engine (DUE) http://www.harmonirib.com

European Commission – Uncertainty Analysis Guidance http://www.harmoni-ca.info/toolbox/Model_Uncertainty/index.php

Great Lakes Commission. 2006. Great Lakes Air Deposition (GLAD) Program Quality Assurance Project Plan Review Checklist Modeling Projects. March. http://www.glc.org/glad/QAPP.html

Hillborn, R., and M. Mangel. 1997. *The Ecological Detective: Confronting Models with Data*. Princeton, New Jersey: Princeton University Press. **To order go to:** http://press.princeton.edu/titles/5987.html

Massachusetts DEP. 2005. Quality Assurance Program Plan - Surface Water Monitoring & Assessment. http://www.mass.gov/dep/water/resources/2005qapp.pdf

Model Uncertainty and Choices Made By Modelers. 2003. Lessons Learned from the International Atomic Energy Agency Model Inter-comparisons. http://www.environmentalfutures.org/Images/LinkovRiskAnal03.pdf

Modeling Course (2006). The Modeling Management Course - Sources of Uncertainty in Modeling. Stony Brook University (SUNY) New York. March.

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

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APPENDIX A - Guidelines for Model Development (EPA 2009)

Note: ***Detailed guidance on model development, evaluation and application may be found in the EPA Council for Regulatory and Environmental Modeling (CREM) document at the following address:*** **http://www.epa.gov/crem/library/cred_guidance_0309.pdf**

Summary of Recommendations for Model Development

►Regulatory models should be continually evaluated as long as they are used.
►Communication between model developers and model users is crucial during model development.
►Each element of the conceptual model should be clearly described (in words, functional expressions, diagrams, and graphs, as necessary), and the science behind each element should be clearly documented.
►When possible, simple competing conceptual models/hypotheses should be tested.
►Sensitivity analysis should be used early and often.
►The optimal level of model complexity should be determined by making appropriate tradeoffs among competing objectives.
►Where possible, model parameters should be characterized using direct measurements of sample populations.
►All input data should meet data quality acceptance criteria in the QA project plan for modeling.

Introduction

Model development begins after problem identification i.e., after identification that an environmental problem needs to be addressed and after determining that models may provide useful input for the decision making needed to address the problem. In this guidance, model development comprises the steps involved in (1) confirming whether a model is, in fact, a useful tool to address the problem; what type of model would be most useful; and whether an existing model can be used for this purpose; as well as (2) developing an appropriate model if one does not already exist. Model development sets the stage for model evaluation, an ongoing process in which evaluates the appropriateness of the existing or new model to help address the environmental problem.

Model development can be viewed as a process with three main steps: (a) specify the environmental problem (or set of issues) the model is intended to address and develop the conceptual model, (b) evaluate or develop the model framework (develop the mathematical model), and (c) parameterize the model to develop the application tool. Model development is a collaborative effort involving model developers, intended users, and decision makers (the "project team"). The perspective and skills of each group are important to develop a model that will provide an appropriate, credible, and defensible basis for addressing the environmental issue of concern.

A "graded approach" should be used throughout the model development process. This involves repeated examination of the scope, rigor, and complexity of the modeling analysis in light of the intended use of results, degree of confidence needed in the results and resource constraints.

APPENDIX B - Useful Project Plan Guidelines for Model Evaluation and Documentation

The following list provides additional useful project plan specifications, as appropriate, for model evaluation and documenting the results of model evaluation as conducted during model development and application (EPA 2009, NRC 2007):

- **Peer review.** Document any critical review of a model or its application conducted by qualified individuals who are independent of those who performed the work, but who collectively have at least equivalent technical expertise to those who performed the original work. Peer review attempts to ensure that the model is technically adequate, competently performed, properly documented, and satisfies established quality requirements through the review of assumptions, calculations, extrapolations, alternate interpretations, methodology, acceptance criteria, and/or conclusions pertaining from a model or its application (modified from EPA 2006a).

  To be most effective and maximize its value, external peer review should begin as early in the model *development* phase as possible (EPA 2006b). Because peer review involves significant time and resources, these allocations must be incorporated into components of the project planning and any related contracts. Peer review in the early stages of model development can help evaluate the conceptual basis of models and potentially save time by redirecting misguided initiatives, identifying alternative approaches, or providing strong technical support for a potentially controversial position (SAB 1993, EPA 1993). Peer review in the later stages of model development is useful as an independent external review of model code (i.e., model verification). External peer review of the *applicability* of a model to a particular set of conditions should be considered well in advance of any decision making, as it helps avoid inappropriate applications of a model for specific regulatory purposes (EPA 1993).
- **Test cases.** Provide for basic model runs where an analytical solution is available or an empirical solution is known with a high degree of confidence to ensure that algorithms and computational processes are implemented correctly.
- **Corroboration of model results with observations.** Include comparison of model results with data collected in the field or laboratory to assess the model's accuracy and improve its performance.
- **Benchmarking against other models.** Include comparison of model results with other similar models.
- **Sensitivity and uncertainty analysis.** Conduct investigation of the parameters or processes that drive model results, as well as the effects of lack of knowledge and other potential sources of error in the model.
- **Model resolution capabilities.** Identify the level of disaggregation of processes and results in the model compared to the resolution needs from the problem statement or model application. The resolution includes the level of spatial, temporal, demographic, or other types of disaggregation.

APPENDIX C - QAPP Guidelines for Use of Models for Comparative Purposes

Occasionally, comparative modeling is used, for example, 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 types of instances, the following should be addressed in the quality assurance project plan (QAPP) and included in a 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, for example, 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