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Systems Analysis of Decision Support Systems for Water Resource Users and Planners in Eastern Ontario

by

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A Thesis

Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Applied Science

in

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Abstract

Increasing attention is being paid to managing water resources on a watershed basis, necessitating a cross-disciplinary approach to data collection and analysis. Traditional assessments of water quality and quantity are being joined by assessments of biology, botany, geomorphology and anthropological subjects such as economic and social criteria. This integrated problem domain calls for a reassessment of the information technology tools designed to support the management process. With a comprehensive requirements analysis including a survey of water resource practitioners, the functions necessary for design of a contemporary Watershed Management Decision Support System (WMDSS) are outlined and assessed in light of current tools in use today.

Following up on a body of research commencing with the Wastewater Allocation Study of the South Nation River [1992] in Eastern Ontario, the problems facing watershed managers are assessed. At the outset of this process, a definition of watershed planning within a management context is necessary. The definition as used by the 1997 Final Report of An Evaluation of Watershed Management In Ontario is employed, as follows: "to provide decision-makers with a broad understanding of ecosystem function and status, and to develop recommendations for appropriate resource management in the watershed." The key points in this definition are firstly that an ecosystem approach is necessary, and secondly that the process must provide an understanding to decision-makers – it is decision support, then, rather than expert system provision, that is required.

Following a systems engineering methodology, the WMDSS requirements are decomposed and ranked in order of priority. This yields a ranking for development of tool and information functional groups to support the following assessment types: surface water quality, surface levels and flows, integration, groundwater flows/levels, rainfall/runoff modelling and time series analysis. Functional analysis then provides the architecture and data flows necessary to meet system requirements: primary sub-systems for management of the database, knowledge base, model base, graphical user interface and output reporting are characterised.

The current state of the science of watershed management is assessed with a view towards meeting the identified system functionality. Subject areas reviewed include physical modelling tools (such as QUAL2E, HEC-RAS and MODFLOW), other models, biological indexes and GIS, decision support systems, integration, software modelling approaches, and the regulatory environment for watershed management. The data input characteristics of key physical models are assessed with a view towards providing an integrated management environment from which a suite of tools can be accessed. Indeed, the primary strength of a WMDSS becomes centralisation of all pertinent information for the watershed in one location, from which interfaces to the suite of physical models are provided. The critical question of how best to relate to GIS systems is also addressed.

With a comprehensive object-oriented analysis and design (OOA/D), the framework necessary for production of a contemporary Watershed Management Decision Support System (WMDSS) is outlined and assessed in light of current tools in use today. The OOA begins by characterising the object models for the primary physical modelling tools that are to be coupled to the WMDSS, those being models for assessment of water quality, surface flows and elevations, groundwater flows and elevations and time series analysis. Physically these models represent the surface and sub-surface hydrological layers of the watershed. Secondly, the integrated nature of a watershed-focused management tool demands that all remaining physical information layers or themes for the watershed be characterised. These include but are not limited to geomorphology, botany, zoology, geology, riparian zones, built up areas (including point sources) and land use designations (non-point sources). By characterising these models and themes a summation object model can be formulated for the WMDSS. This object model then becomes the foundation for the follow-on OOD process.

The OOD process requires that the outlined summation object model be realised in code, forming the basis for the WMDSS. Built upon this object model is all of the functionality necessary to satisfy the identified requirements for the system. The OOD architecture follows broadly from the three primary sub-systems: database management, model base management and knowledge base management.

The critical validation phase uses an analysis of the South Nation basin to confirm that the system developed meets stated requirements by determining the relative importance of point and non-point sources to the river's water quality. The 1992 study concluded that on an annual basis the major sources of ammonia and phosphorus were non-point sources, to the extent that nitrogen and phosphorus loads contributed by these non-point sources constituted greater than 98 and 93%, respectively, of the total load. Growth figures produced at the time, forecast a doubling of the watershed population by 2001, generating grave concerns that the assimilative capacity of the river would be greatly exceeded. Validation of these figures will give clear emphasis on the necessity of addressing water quality in the basin through non-point source abatement measures, the success of which are central to removing wastewater assimilative capacity as a growth limiting factor for the region.

Analysis of the basin through WMDSS requires construction of the physical representation of the basin, followed by characterisation of its water quality constituent characteristics. Knowledge of all point source inputs and withdrawals from the system leaves the non-point sources as the undefined water quality source term to be estimated through analysis. The populated WMDSS serves as the management framework from which water quality modelling iterations are launched. The physical water quality model being used for the simulations is QUAL2E. This permits comparison to the 1992 study results, wherein a modified Streeter–Phelps equation incorporating nitrogenous and sediment oxygen demands was used to characterise dissolved oxygen variations. Physical limitations of the QUAL2E model require that several sub-watershed sections of the South Nation basin be modelled separately, with their results added as necessary. Differences between the 1992 results and the WMDSS results are explained through comparison of the equations used and of the physical watershed representations in each of the studies.

The thesis concludes with a summary of the two studies comparison and validation of the WMDSS concept as an effective watershed management approach.

Acknowledgements

I would like to thank my supervisor Dr. Ron Droste for his support and keen interest in this project, as well as for the financial support under a Research Assistanceship. Additionally I would like to thank the members of my user group, whose feedback was essential in executing this project.

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Abbreviations

CA – Conservation Authority

DBMS – Database Management System

DSS – Decision Support System

EI – Ecological Index

EPA – Environmental Protection Agency

GIS – Geographical Information System

GUI – Graphical User Interface

HEC – Hydrologic Engineering Center

HMS – Hydrologic Modelling System

IDE – Integrated Development Environment

IT – Information Technology

KMBS – Knowledge Base Management System

MBMS – Model Base Management System

NGO - Non-government Organization

NPS – Non-point Source

OM – Object Model

OOA – Object-Oriented Analysis

OOA/D – Object-Oriented Analysis/Design

OOD – Object-Oriented Design

PMTE – Process-Methods-Tools-Environment

QUAL2E – Enhanced Stream Water Quality Model

RAS – River Analysis System

WMDSS – Watershed Management Decision Support System

Chapter 1. Introduction

The decisions made by water resource planners and users are important and carry wide ranging consequences. They often result in changes to water resource systems with impacts over decades, and result in significant expenditures of public and private funds. Providing background and planning assistance to inform decision-makers is a time consuming and inexact process. As a result, a significant body of work has focused on the provision of Decision Support Systems (DSS) for water resource planners and users. Today, there are few technical limits to the provision of information technology (IT) based DSS; limitations fall rather in the realms of cost and level of production effort.

Production of a DSS will likely pay for itself when the cost is amortized over the future period in which the decision-making period is assisted by the DSS, reducing the time and resources that need to be allocated. Under an open architecture methodology, a DSS (if sufficiently user friendly) can be specifically tailored to the needs of municipal and regional planners, growing with the user to embrace new and changing applications. The DSS will need to bring with it a broad and flexible toolset, such that it can accommodate a wide range of potential users. It will also have to contend with a range of data inputs from complete and comprehensive to sparse.

While this growing list of requirements may look unachievable, it must be remembered that a DSS will not in itself have to solve all of the physical problems – it will instead couple together tools, including existing models, which together can assist decision-making. To limit the scope of this endeavour, and to address the needs of likely end users, focus will be drawn to the problems faced by planners in the Eastern Ontario region. This confines consideration of models to those applicable to analysis of generally flat agricultural watersheds.

1.1. Watershed Management

At the outset of this project, a definition of watershed planning within a management context is necessary. The definition appearing in the 1997 Final Report of An Evaluation of Watershed Management In Ontario [PMC, 1997] will be used, i.e., "to provide decision-makers with a broad understanding of ecosystem function and status, and to develop recommendations for appropriate resource management in the watershed." The key points in this definition are firstly that an ecosystem approach is necessary, and secondly that the process must provide an understanding to decision-makers – it is decision support to a manager within the decision loop, then, that is required.

1.2. Thesis Organisation

A shortcoming of past initiatives for the provision of DSS has been to enter the problem definition and solution generation process too far into the loop. A detailed understanding of the needs of system users is therefore missed, resulting in an ad hoc approach to solution generation. Rather than trying to fit solutions to problems, the problems must be thoroughly defined through a requirements analysis. This approach is best suited to a systems engineering methodology carried out within the broader systems analysis, reinforced by the mapping of user needs onto an IT solution architecture. The steps in such a systems analysis are as follows:

1. Characterise Non-physical Problem Boundary Condition Process Inputs (c.f. Figure 2-3).
2. Perform Systems Analysis, as follows:
   (a) Analyse User Requirements;
   (b) Map Requirements to Functions; and
   (c) Synthesize Functions.
3. Define Process Outputs (Decision Support).
4. Characterise Physical Problem Boundary Condition Process Inputs.

The systems analysis process is also an iterative process, as findings of later steps will warrant a revision of earlier steps. From a project perspective, this task has been broken into six phases, as follows:

1. Define Problem First Iteration.
2. Obtain Background Knowledge.
3. Define Problem Second Iteration.
4. Produce Data and Object Models (object-oriented analysis).
5. Produce Program Code (object-oriented design).
6. Validate DSS with Real World Problem.

Each of the phases is briefly described in the following paragraphs. A final note concerns the relative weightings of the systems analysis and software production portions of the project. The nature of the project is such that the software source code of the DSS is not included as part of the thesis, however an Alpha proof of concept demonstrating all key functionalities is produced and has been used for the validation in Phase 6.

1.3. Phase 1: Initial Problem Definition

In this phase, the problem is defined on a 'first principles' basis. Using a systems analysis methodology, the broad requirements driving DSS are examined. Firstly, process inputs to the water resource planner decision making sphere are investigated. Such inputs include provincial and municipal water quality regulations, water resource planner levels of expertise and staff assistance, and typical planning cycles at municipalities and regional authorities. Detailed user requirements are confirmed through a mail out questionnaire (included as Annex A – see Chapter 4), these requirements subsequently being mapped to system functions and the functions synthesized into a comprehensive data model.

This phase is reported on in Chapter 2.

1.4. *Phase 2: Obtain Background Knowledge*

In this phase, necessary background knowledge in appropriate subject areas is obtained. Two broad categories investigated are as follows:

1. Literature Search. Current research papers in the field of water resource planning were investigated. Sub-categories of interest are as follows:

   (a) Current Watershed DSS Efforts.

   (b) Mathematical/Numerical Models (Toolset), including costs and availability (e.g., HEC-HMS, AGNPS), and recommendations for in-house estimation methods in the event that existing models are too costly or unavailable. Types of interest include:

      i. Water Quality, covering point and non-point sources;

      ii. Water Quantity;

      iii. Ground water Quality and Quantity;

      iv. Rainfall/Runoff Modelling;

      v. Sediment Transport;

      vi. Ecological/Biological Indices; and

      vii. Integration Tools.

   (c) Software Modelling Approaches including Object-Oriented Analysis/Design (OOA/D).

   (d) Legislative Environment (Regulations).

   (e) Other DSS Efforts.

2. Software. Pertinent subjects as follows:

(a) Object-Oriented Programming (e.g., Smalltalk);

(b) Event-based Programming (e.g., Visual Basic); and

(c) Geographic Information Systems (e.g., ArcView, Grassland).

This phase is reported on in Chapter 3.

1.5. Phase 3: Final Problem Definition

Having completed the background research, the requirements capturing of Phase 1 is revisited with a view towards decomposition of the results. All of the collected user requirements are analysed, and the functional mapping and synthesis is performed. The DSS outputs are then defined (what decisions are supported – what questions are answered, e.g., changes in treatment for municipal wastewater treatment facilities that are not achieving standards, changes to facultative pond discharge windows/durations, changes to effluent discharge locations to meet satisfactory dilution levels, setting of water withdrawal levels for new industrial users, estimates of future water/wastewater treatment needs to begin the capital savings process, etc.). The final step of characterising the physical problem space for Eastern Ontario is left to the validation phase.

The key step in this phase is in the formulation of the data model of the proposed DSS. **This data model is the key deliverable of this project**, forming the foundation of the subsequent phases and any follow-on work proposed. The data model involves the incorporation of the mathematical/numerical model data requirements determined in Phase 2 into a decision support system.

This phase is reported on in Chapter 4.

1.6. Phase 4: Produce Object Model (Object-Oriented Analysis)

In this phase, the data model from Phase 3 is complimented with an object model through an Object-Oriented Analysis (OOA). A comprehensive product from Phase 3 makes this a straightforward process of characterising the watershed themes and mapping their interrelationships as previously defined. The object model resides within the overall system as the foundation on which the data model operates.

Initial investigation of this project [Spanou, 1995; Gore & Storrie, 1992] indicated that it is naturally suited to an object-oriented problem solving methodology. Indeed, the concept of coupling various models into input/process/output chains is itself readily definable through an object-oriented approach. A key component of the OOA involves analysis of existing model input/output formats, and the Database Management System (DBMS) necessary to tie them together. The object model specification becomes the template for production of the WMDSS database.

This phase is reported on in Chapter 5.

1.7. Phase 5: Produce Program Code (Object-Oriented Design)

In this phase, the outputs of Phases 3 and 4 are programmed, using an Object-Oriented Design (OOD) methodology. The software used is Visual Basic, Version 5. The OOD methodology results in a Windows based product with an intuitive GUI, suitable for a range of users bringing with them varying levels of subject knowledge and computer expertise.

As previously stated, the design effort has focused on producing an Alpha proof of concept, that being a stage of development that demonstrates the required functionality without having the error trapping and user friendliness associated with a more mature product. All necessary steps in taking the software to the Beta stage have been outlined in this phase. The data model is produced in code through a combination of forms and general modules, while the object model is achieved through the creation of class modules (instantiation templates).

This phase is reported on in Chapter 6.

1.8. Phase 6: Validate Tool with Real World Problem

No design and development process is complete without a validation phase. This is accomplished by providing decision support to a water resource planner question in Eastern Ontario. For the purposes of this study the South Nation River watershed was chosen, given its foundation as the watershed from the Gore & Storrie study of 1992 that was used in past efforts at the University of Ottawa to design watershed tools.

The primary aim of this phase is to validate the system design in meeting requirements and to verify the implementation of the data model produced in Phase 3 and the object model produced in Phase 4. The secondary aim is to seek user feedback on the first version of the DSS software tool.

This phase is reported on in Chapter 7.

Chapter 2. Initial Problem Definition: The Watershed Management Decision Support System

In support of the systems analysis objective of approaching this problem from a broad perspective, a first attempt at defining the problem is needed. As well, a method of organising the problem into logical solution steps is needed – formal systems engineering satisfies this requirement.

2.1. Systems Engineering Methodology

The approach taken in the execution of this project is a systems engineering approach, defined as follows, "an overall process used to translate an operational need into a working system that satisfies the requirement" [Martin, 1994]. In satisfaction of this approach, the Process-Methods-Tools-Environment (PMTE) Paradigm [Martin, 1994] will be adhered to, broken down as follows:

1. <u>Process</u>. A logical sequence of tasks performed to achieve a particular objective.
2. <u>Methods</u>. Techniques used to perform tasks, for example:
    (a) Observation;
    (b) Analysis;
    (c) Synthesis;
    (d) Optimisation;
    (e) Documentation; and
    (f) Communication
3. <u>Tools</u>. Instruments applied to a method to improve its efficiency.
4. <u>Environment</u>. Surroundings, external objects, conditions, factors that influence actions of an object, person, or group, for example:

(a) Social;

(b) Cultural;

(c) Personal;

(d) Physical;

(e) Organizational; and

(f) Functional

The PMTE Paradigm can be viewed graphically as a series of concentric circles, as shown in Figure 2-1. An overall process for Systems Engineering can also be depicted graphically, as shown in Figure 2-2. This is the process that has been used to define the phases of the project as described previously, with Phase 1 being a first attempt at the complete cycle. It is also the process on which the DSS will be broadly based, as it provides a logically consistent and thorough methodology highly applicable to decision making in water resources management.

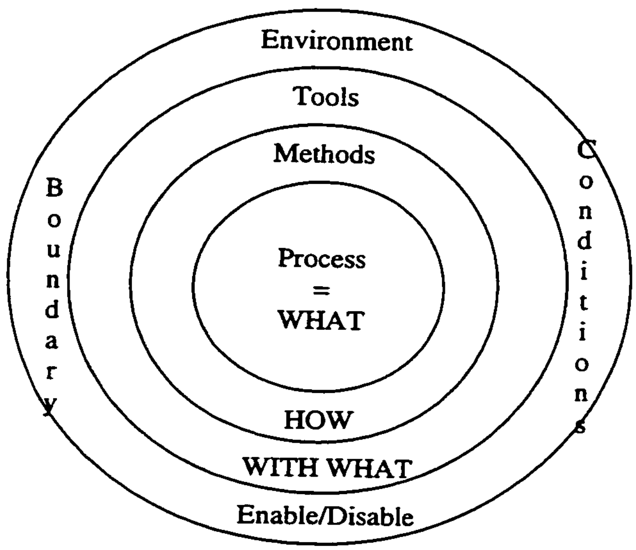


Figure 2-1. The PMTE Paradigm [after Martin, 1994]

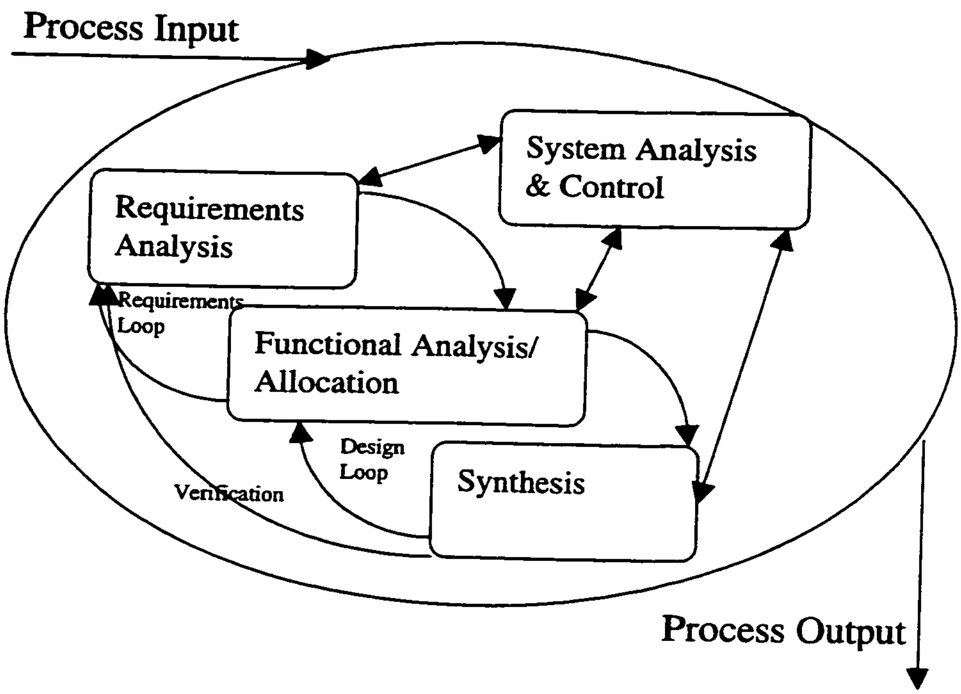


Figure 2-2. The Systems Engineering Process [after MIL-STD 499B, 1996]

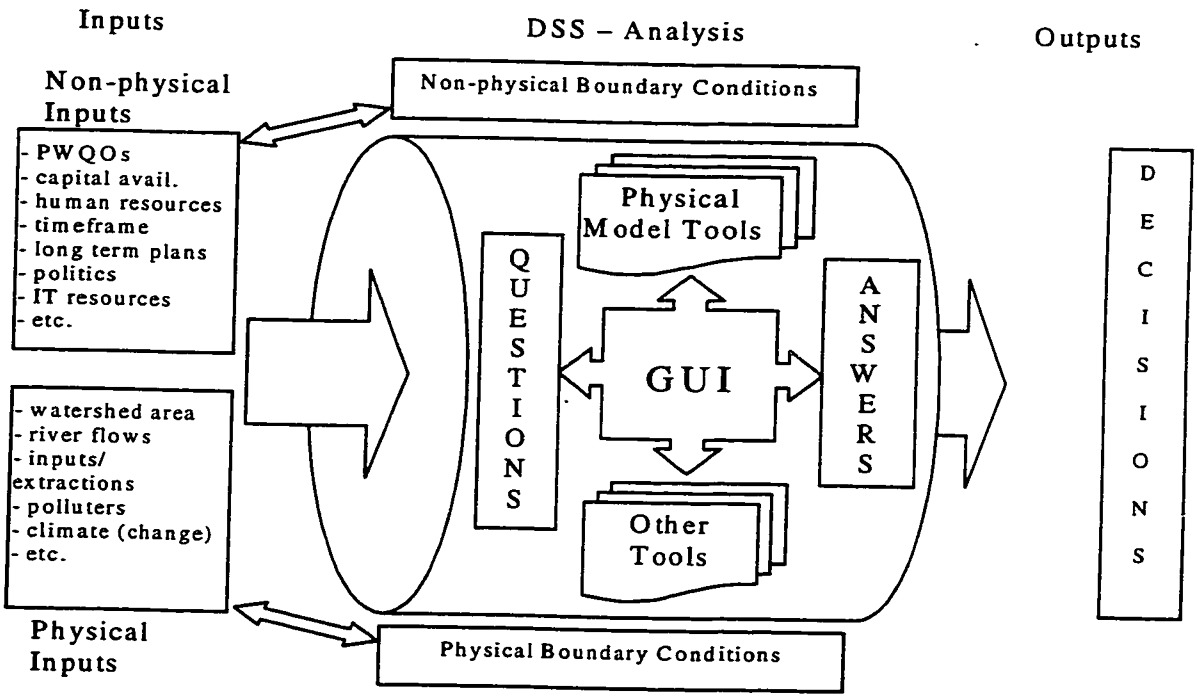


Figure 2-3. A Systems View of the DSS

2.2. Systems View of Problem Space

To orient the problem within the process described in the previous section, Figures 2-3 and 2-4 have been developed to describe its conceptualisation. Of note is the fact that this is a manager-in-the-loop system, where WMDSS provides answers to questions that are part of an overall decision making process. This effort is focused on building the GUI lying at the heart of the system.

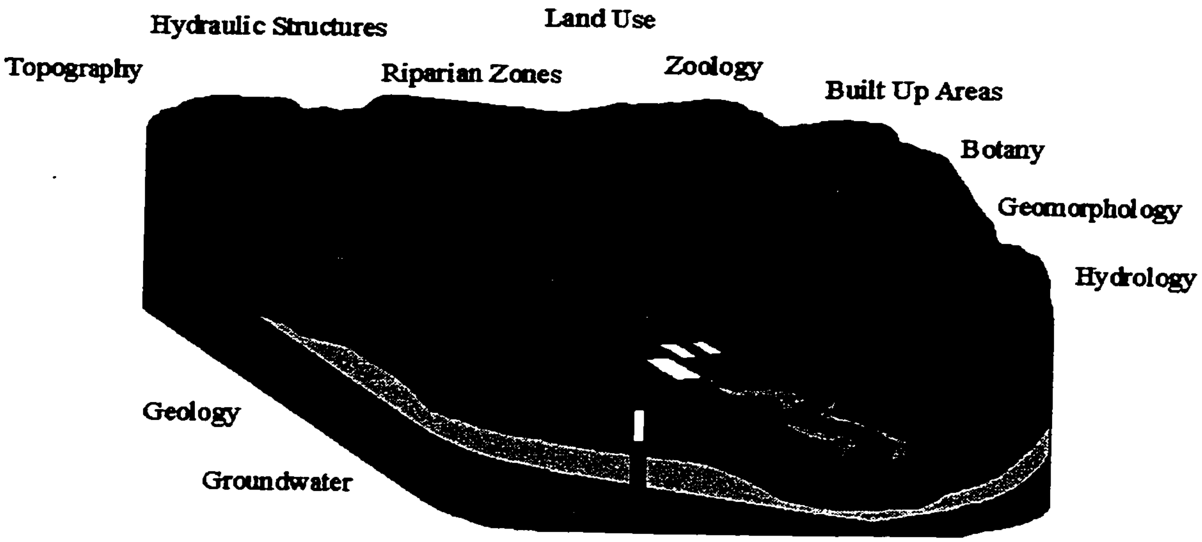


Figure 2-4. Concept for a Watershed

In Figure 2-4 the watershed is viewed from a physically exact perspective as an amalgam of constituent themes. Rather than limiting conceptualisation to themes that can be linked to analysis tools, all themes are included. In this manner, themes that are important in providing information on the watershed but have limited analysis support through tools can be identified, lending support towards efforts aimed at filling the need. This view defines a watershed in terms of its constituent objects. Another view could be to define a watershed in terms of its constituent processes, for example for hydrology this includes precipitation, evapotranspiration, runoff, infiltration, sediment transport, chemical constituent fate and transport, etc. The object-oriented approach is easily visualised and is comprehensive in its coverage of the watershed.

2.3. Process Inputs to Water Resource Management

Taking the general system from Figure 2-3, non-physical inputs and boundary conditions plus physical inputs and boundary conditions constitute the process inputs, i.e., the regulatory, financial, temporal, practical and physical environment in which water resource decisions are made. The following inputs are produced:

1. Regulatory
   (a) Federal water quality regulations [Environment Canada CWA, 1984],
   (b) Provincial water quality regulations [MOEE, 1995],
   (c) Municipal water quality regulations, and
   (d) Point source Certificates of Approval from MOEE;
2. Financial
   (a) Municipal budgets,
   (b) Provincial grants,
   (c) Project capital costs,
   (d) Remediation costs, and
   (e) Study/consultant costs;
3. Temporal
   (a) Typical planning cycles at municipalities, and
   (b) Typical planning cycles at regional authorities;
4. Practical
   (a) Water resource planner levels of expertise,

(b) Level of staff assistance, and

(c) IT resources available;

5. Physical (water resources as an example)

   (a) Surface water inflows,

   (b) Ground water inflows,

   (c) Infiltration,

   (d) User water/wastewater discharges,

   (e) User water withdrawals,

   (f) Evaporation,

   (g) Transpiration,

   (h) Surface water outflows, and

   (i) Ground water outflows.

Within the PMTE Paradigm, process inputs are grouped according to the following headings:

1. Social;

2. Cultural;

3. Personal;

4. Physical;

5. Organizational; and

6. Functional

Either categorisation of process inputs will suffice to organise and define them. The user mail out questionnaire (Appendix A) includes questions designed to confirm the process inputs relevant to water resource problems in Eastern Ontario – see Section 4.1 for details.

2.4. Requirements Analysis

In order to conduct a requirements analysis, it is important to first define some key terminology. For this, the Watershed Planning Implementation Project Management Committee final report of an evaluation of watershed management in Ontario is referenced [PMC, 1997]. The hydrogeographic context in which water resource decisions are made is the watershed, defined as the entire catchment area, both land and water, drained by a watercourse and its tributaries. A subwatershed is the catchment area drained by individual tributaries to main watercourses. The PMC report calls for ecosystem management, following a sustainable use vision. Watershed management then becomes the process of managing human activities in an area defined by watershed boundaries in order to protect and rehabilitate land and water and associated aquatic and terrestrial resources, while recognizing the benefits to orderly growth and development. It is a process which involves Conservation Authorities (CA), municipalities, developer landowners (at the request of approving agencies), provincial agencies in fulfilling their mandates to protect and preserve the environment, federal programs for designation of heritage areas, and community driven initiatives [PMC, 1997]. The drivers behind watershed projects include environmental resources, land use changes, land use management, and redevelopment/restoration efforts such as habitat restoration, pollution abatement and environmental enhancement options.

As a first step in capturing the broad requirements applying to a DSS for water resource users and planners, the key stakeholders and their interests can be examined, as follows [after PMC, 1997]:

1. <u>Government Agencies</u>. Including local (CA and municipalities), provincial and federal.

(a) Prepare realistic and achievable long term resource management plans,

(b) Protect, enhance and restore fish and other aquatic resources,

(c) Protect water quality,

(d) Protect water quantity,

(e) Develop private and municipal water and sewage services,

(f) Identify future development opportunities,

(g) Conduct land management activities,

(h) Identify and protect wetlands,

(i) Work in cooperation with the land use planning system, and

(j) Reduce the cost of remediation;

2. Affected Parties. Including individuals/groups whose lifestyles or business or land use occupance practices may be positively or negatively impacted by watershed management decisions.

(a) Represent views of landowners and the agricultural community,

(b) Protect resources from land use changes,

(c) Improve water quality and quantity,

(d) Prevent environmental degradation,

(e) Address private landowner rights,

(f) Streamline the approvals process, and

(g) Reduce barriers to development, protection and management in watersheds;

3. Special Interest Groups (SIG). Including 'friends of' groups (e.g., U.S. National Watershed Network [Keppy, 1997]) and NGOs.

   (a) Protect recreational green space, and

   (b) Establish criteria for development and land use changes; and

4. Community Members. Residents of the watershed.

   (a) Restore water quality and ecosystem integrity.

The above needs now must be reworked into a logical categorisation. Options are to group by organisation or by subject. The latter was adopted initially, resulting in broad requirements as follows:

1. assist in the assessment of:

   (a) water quantity (e.g., using an approach as shown in Figure 2-5), and

   (b) water quality;

2. support remediation planning for:

   (a) in stream, and

   (b) riparian zone.

3. support protection planning of:

   (a) water quality,

   (b) water quantity, and

   (c) ecosystems.

4. support pollution prevention planning; and

5. support watershed management administration efforts by:

(a) providing planning guidance documentation/information,

(b) providing a mechanism to resolve inter-jurisdictional disputes, and

(c) assisting in minimising capital outlays through optimisation.

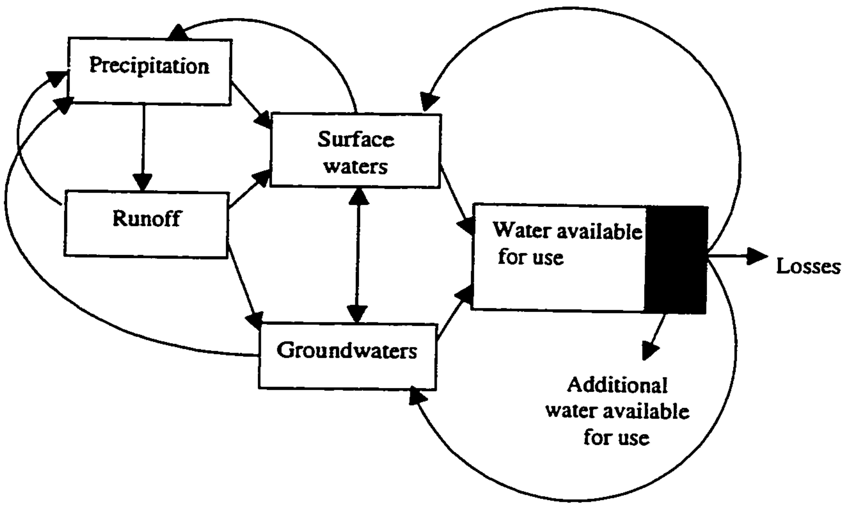


Figure 2-5. Water resources management balance approach [after Miloradov et al., 1995]

A proper requirements analysis necessitates taking these broad requirements and breaking them down into their sub-requirements such that a functionality mapping can be done.

These topics are logically left to Sections 4.3 to 4.7 for treatment, after the system requirements have been confirmed.

Chapter 3. Background Knowledge

This section summarizes the findings of the initial background information gathering process. It is organised by first covering the tools that are available to water resource planners, and then examining the non-physical boundary conditions which influence the problem space of water resources. It is meant to offer information to support the design of the complete WMDSS beyond the implementation carried out within this thesis.

A number of schemes have been used to organise and describe modelling tools. The definitions used herein will be as per the descriptions by James [1993]. The general approach to modelling involves two broad stages: analysis of the system, and synthesis of a mathematical replica of the system [James, 1993]. The steps taken in the formulation of a model are shown in Figure 3-1. Critical in commencing the modelling process is the establishment of clear objectives against which the model can be measured to determine success. Next, the theoretical background governing the physical system must be reviewed and updated with the latest information. Then the actual model can be formulated, beginning with a decision about the type of model that best meshes the objectives to the physical problem space.

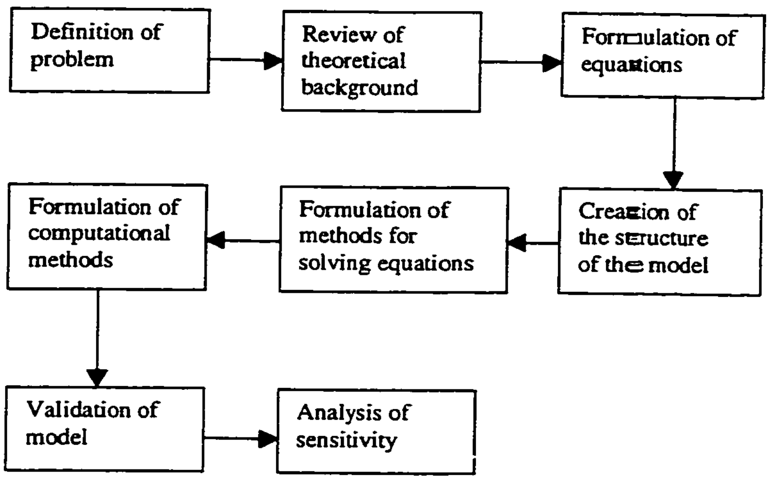


Figure 3-1. Diagrammatic representation of the steps in creating simulations [after James, 1993]

The model structure is created next, generally using a top down approach with major model subdivisions being defined and further broken down into constituent elements. These elements will need to be represented by (an) equation(s). The necessary input data and information flow can be mapped to the structure. Solution techniques must be selected: while exact analytical solutions are preferred, the complex nature of most mathematical models describing water quality will require numerical solution techniques. Final steps involve the production of the actual computer program with the critical calibration, validation and sensitivity analysis processes following. The expansion in use of IT to provide modelling support has resulted in multiple approaches to system design and model types. Figure 3-2 illustrates this in the context of environmental decision making, and Figure 3-3 offers further insights into how models used in the analysis of water quality (as an example) are classified.

While each modelling scenario will pose individual problems, a common source of difficulty lies in establishing the key governing equations that characterize the problem. Over simplification can lead to a poor, inexact result, while too much complexity can lead to increased costs and time consumption and a reduction of flexibility.

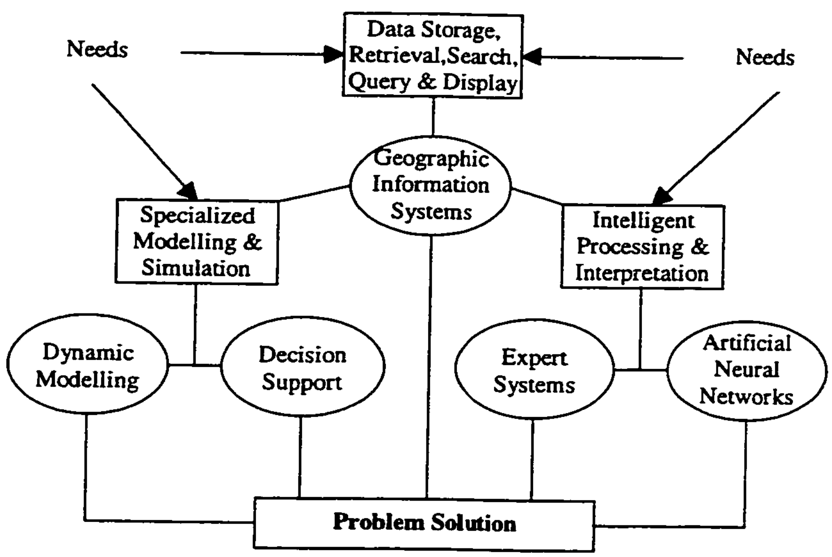


Figure 3-2. Information Technology System Design [after Lein, 1997]

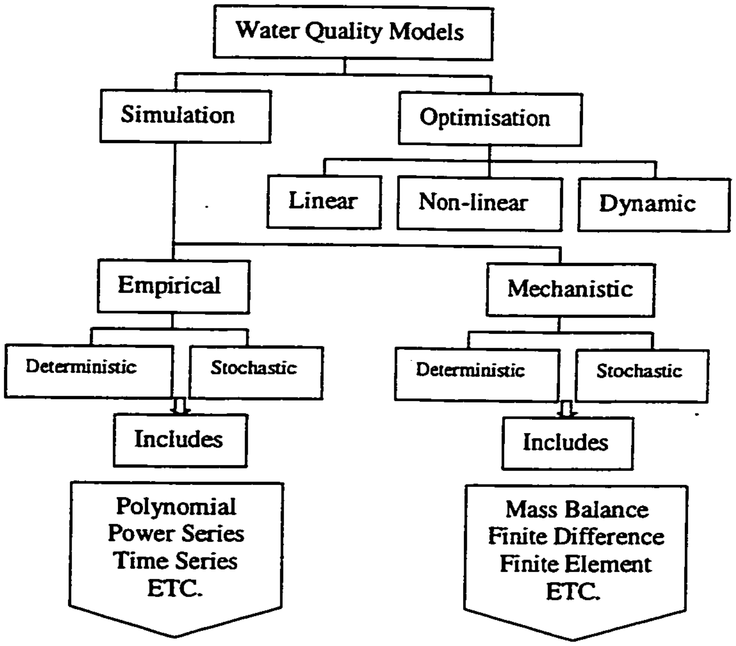


Figure 3-3. Classification Scheme for Water Quality Model Types [after James, 1993]

In this analysis, models also need to be differentiated according to what aspect of the watershed they model, be it surface flows, ground water flows, chemical constituents, biological processes, etc. Sections 3.1 and 3.2 will cover these in more detail. The last introductory concept to cover is to place decision support within the context of IT support to environmental problem solving. Looking at Figure 3-2, it can be seen that decision support joins dynamic modelling, expert systems and artificial neural networks as the approaches to problem solving in this domain. These are individual and complementary approaches, defined as follows [Lein, 1997]:

1. Decision Support. An IT system that recognises the capabilities of a computer to support decision makers through such functions as access to data and models for problem formulation and alternative evaluation.

2. Dynamic Modelling. An IT model representing a system in a time-varying state, such that inputs and coefficients may vary with time, giving rise to a time-varying output.

3. Expert Systems. An IT system with the capacity to perform reasoning operations using human expert knowledge-based rules.

4. Artificial Neural Networks. An IT system that simulates the functionality of the human brain in decision making.

Looking at the features and user requirements for these four approaches demonstrates the rationale for using the first approach for this project. Both expert systems and artificial neural networks are disregarded here due to the fact that they represent systems that aim to replace the manager in the decision process. Both of these approaches mimic the decision making process of a human, either through replication of a rules based paradigm (expert systems) or through use of a network of data linkages (artificial neural networks). Dynamic models are infrequently used as operational models supporting the problem solving process for water resource users and planners, though they may well play a component role as one of the models coupled to the system. This then leaves decision support as the approach of choice. Decision support borrows heavily from systems theory in its representations of and solving methodologies for problems – hence the approach taken in this project.

3.1. Physical Models

Having placed decision support systems within the broader context of IT tools, the next step down is to examine some of the physical models that a decision support system can draw upon in its toolset to help support decision makers. Models need to be assessed based on such criteria as the subject of the model, its data requirements, its availability (cost), its user friendliness and its ability to be integrated into a decision support system (DSS). Application-focused models can be broken down by subject area, as discussed earlier, and can be categorised as either digital process models, spreadsheet systems, or general purpose simulation programs [Lein, 1997] – not forgetting analytical models on which many of the digital models are based. The bulk of physical models familiar to environmental practitioners fall into the first category of digital process models, those being models developed to simulate key environmental processes. Table 3-1 summarizes a number of digital process models for water quality, surface flows, rainfall/runoff, subsurface hydrology, and sediment transport, and online databases and watershed management programs.

Subject	Name	Type/Sys Req	Source	Characteristics	Availability
Water Quality	QUAL2E Sep 95	PC-WIN DNS	US EPA Watershed Modeling Section 401 M Street, S.W. Washington, DC 20460	Simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance.	Free - download at http: //www. epa.gov
	AGNPS 98	PC-WIN DPM	ARS National Sedimentation Laboratory Oxford, Mississippi	Simulates sediment and nutrient transport from agricultural watersheds; the basic components of the model are hydrology, erosion, sediment transport, nutrient transport, and chemical oxygen demand.	Free - download at http://www.sedlab.olemis.edu/AGNPS98.html
	CORMIX 3.2 Dec 96	PC-DOS DPM	US EPA-CEAM960 College Stn Rd Athens, GA 30605-2700	Analysis, prediction and design of aqueous toxic conventional pollutant discharge into diverse water bodies.	Available at no charge via CEAM disk exchange or download at http://ftp.epa.gov/epa_ceam/wwwhtml
	SWAT 98.1	PC-WIN95	Grassland, Soil and Water Research Laboratory Temple, TX.	SWAT is a continuous time model (daily time step) that is required to look at long-term impacts of management (i.e., reservoir sedimentation over 50-100 years) and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing).	Free – download at http://www.brc.tamus.edu/swat/swat/swatdoc.html
	WASP5 93	PC-DOS DPM	US EPA	Contaminant fate and transport model in 1-D, 2-D, 3-D.	Available at no charge via CEAM disk exchange or download at http://ftp.epa.gov/epa_ceam/wwwhtml

Surface Flows	HEC–2	PC-DOS DPM	Hydrologic Engineering Center Davis, CA	Water surface elevation profiles.	Free – download at http://wrc-hec.usace.army.mil/software/software_distrib/index.html
	HSCTM2D	PC-DOS DPM	CEAM	2-D vertically integrated surface water flow, sediment transport and contaminant transport modelling suite	Available at no charge via CEAM disk exchange or download at http://ftp.epa.gov/epa_ceam/wwwhtml
	HEC-RAS 2.1	DPM – Win95	Hydrologic Engineering Center Davis, CA	Water surface profiles program; mixed flow regime analysis, allowing analysis of both sub- and super-critical flow regimes	Free – download at http://wrc-hec.usace.army.mil/software/software_distrib/index.html
	SWMM	PC-DOS DPM Also in EX version for Expert System	US EPA - CEAM	SWMM is a large, complex model capable of simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units and finally to receiving waters. Both single-event and continuous simulation may be performed on catchments having storm sewers and natural drainage, for prediction of flows, stages and pollutant concentrations.	Available at no charge via CEAM disk exchange or download at http://ftp.epa.gov/epa_ceam/wwwhtml

	SMADA	DPM		Complete hydrology package included as a number of separate executable files. These programs work together to allow hydrograph generation, pond routing, storm sewer design, statisitical distribution and regression analysis, pollutant loading modeling, matrix calculation, and others	Free - download at http: //www-cee.engr.ucf.edu/
	MIDUSS	DPM		Stormwater runoff program for the design and collection of a network of storm sewers/channels	Alan A Smith $US 595
Rainfall/ Runoff	HEC–1	PC-DOS DPM	Hydrologic Engineering Center Davis, CA	Rainfall analysis and discharge calculation.	Free – download at http://wrc-hec.usace.army.mil/software/software_distrib/index.html
	HEC-HMS	PC-WIN DPM	Water Resources Consulting Services 3145 Geary Blvd. #615 San Francisco, CA 94118	Precipitation-runoff simulation.	$95 US downloadable w/ manuals at http://www.waterengr.com/hms.htm

Subsurface Hydrology	MOD-FLOW 96 MFI MODPATH ZONE-BUDGET	Modular 3-D finite-difference ground water flow model	U.S. Geological Survey Hydrologic Analysis Software Support Program 437 National Center Preston, VA 20192	This code is a block – centred finite difference code that can simulate a range of aquifer types. MFI - Data input program for MODFLOW, MODPATH, and MOC3D MODPATH - A particle-tracking postprocessor model for MODFLOW (Unix only) ZONEBUDGET - Program for computing subregional water budgets for MODFLOW ground-water flow models	http://water.usgs.gov/software/modflow-96.html (electronic mail: h2osoft@usgs.gov)
	FEM-WATER	PC-DOS DPM	CEAM	Flow and transport in 3-D variably saturated porous media under transient conditions with multiple sources and sinks.	Available at no charge via CEAM disk exchange or download at http://ftp.epa.gov/epa_ceam/wwwhtml/femwater.html
	PLASM	2-D finite difference flow model	Thomas A. Prickett & Assoc. 6 GH Baker Dr. Urbana, Ill. 61801	The Prickett-Lonnqiust Aquifer Simulation Model is a block-centred finite difference code that can simulate 2-D problems in both areal and profile orientation.	$150 US
Sediment Transport	FESWMS – 2DH	2-D finite element flow model	US Federal Highways	Uses primitive vertically averaged Navier Stokes shallow water eqn.	Public domain
	HEC-6	PC-DOS DPM	Hydrologic Engineering Center Davis, CA	Modelling of scour and sediment deposition in rivers and reservoirs.	Free – download at http://wrc-hec.usace.army.mil/software/software_distrib/index.html

	CH2D	2-D finite difference flow model	WES	Uses primitive shallow water eqn.	Public domain
Online Databases	STORET	Dial-up site	US EPA	Repository for water quality and environmental monitoring data; chemical, physical and biological data pertaining to quality of US waterways	Account required
Watershed Manage-ment	DESERT	PC-WIN	IIASA	Decision support for water quality management on a river basin scale. Features: data management, model calibration, simulation, optimization, plotting results of simulation, friendly user environment based upon Microsoft Windows interface.	http://www.iiasa.ac.at/Research/WAT/docs/desert.html
	BASINS 2.0	ArcVIEW script program	US EPA	BASINS version 2.0 is a customized ArcView GIS application that integrates environmental data, analysis tools, and modeling systems.	Public domain
	RAISON	Regional Analysis by Intelligent Systems ON microcom puters – Expert System	Coordinator NWRI Software National Water Research Institute Environment Canada 867 Lakeshore Road, P.O. Box 5050 Burlington, Ontario, Canada L7R 4A6	a data analysis tool that provides an intuitive environment for displaying data and analyses in the context of the local geography	

Notes: 1. DPM = Digital Process Model

2. DNS = Deterministic Numerical Simulation

3. General approach: find common, validated, inexpensive modelling tools running on a PC.

Table 3-1. Physical Models of Interest to Watershed Management

It is also worth mentioning the use of 1-D codes or spreadsheet models for particular physical problems encountered within watersheds. It is necessary to weigh the additional cost of a digital process model in terms of the time and expertise required to use it against the increase in precision of the results it provides. In many instances it may be sufficient to employ a simple 1-D code or a spreadsheet to produce a '90%' solution to a problem, rather than investing the resources necessary to produce a '95%' solution. A good example of this is in the case of making rapid time-of-travel estimates for emergency contaminant spills – rapid estimates gained through use of empirical estimates offer the best approach [Jobson, 1997]. 1-D codes or spreadsheet solutions are available for all conceivable physical watershed problems, such as ground water flow [Anderson and Woessner pp.23–4, 1992], oxygen sag, river flow with dispersion and moving segments, discharge to a river, lake thermal structure, lake hydrodynamics, lake chemistry and lake biology [James, 1993].

The models listed in Table 3-1 were evaluated as to their suitability for inclusion in the WMDSS. QUAL2E, AGNPS and WASP5 were suitable water quality models for modelling dendritic systems. Of these three, QUAL2E has the simplest interface requirement, in that it relies on a single plain text input file (under the Windows version). It is also preferable due to the prevalence of its use. HEC-2, HEC-RAS and SWMM met the criteria of being free, validated, and relatively simple to interface with for surface water flow and profile modelling. HEC-RAS additionally offers a GIS interface and will soon provide sediment transport features, and so was selected. For rainfall/runoff modelling, HEC-HMS is the improved version of HEC-1 and so was selected. Finally, for sub-surface hydrology MODFLOW was selected due to its widespread use and easy access to source code. It should be made clear here that the selection of models is not exclusive, i.e. any model with user support that can be coupled into a management system is of potential consideration. For this reason, the user mail out questionnaire gathered information on the models in use in the Eastern Ontario region.

3.2. Other Models

There are a multitude of other elements that combine to form the watershed view of interest to managers, aside from the physical characteristics mentioned in Section 3.1. These include the following [after Lein, 1997]:

1. Botany. Elements such as:

(a) species diversity/species of interest/trends; and

(b) structure.

2. Geology. Elements such as:

   (a) lithology; and

   (b) structure.

3. Human. Elements such as:

   (a) inhabitance (subset of land use)/trends in populations;

   (b) culture;

   (c) economy/economic value of watershed elements; and

   (d) land use/land use trends.

4. Climate. Elements such as:

   (a) weather elements;

   (b) patterns;

   (c) precipitation levels/seasonal variations/trends.

5. Zoology. Elements such as:

   (a) species diversity/species of interest/trends;

   (b) food webs; and

   (c) patterns.

It is anticipated that models exist for many of the above listed elements. They find infrequent use in generalised watershed management systems such as those reviewed in Table 3-1, being overly specific to be of general use. Specialised problems do make use of some specialised models – recent efforts to examine the sensitivity of basins to climate change, for example, have made good use of the GOLEM model [Tucker and Slingerland, 1997]. The above elements do however find expression through grouped or ecosystem-based measures. One method of accomplishing this is through use of indices – see Section 3.4 for further details on indices. The trend towards development of integrated systems will give increasing weight on methods of successfully incorporating a large range of elements into a management system – this is both the bane and the challenge of contemporary watershed decision support system designers.

Models also exist for ecosystems. One such model is an energy flow model, as depicted in Figure 3-4.

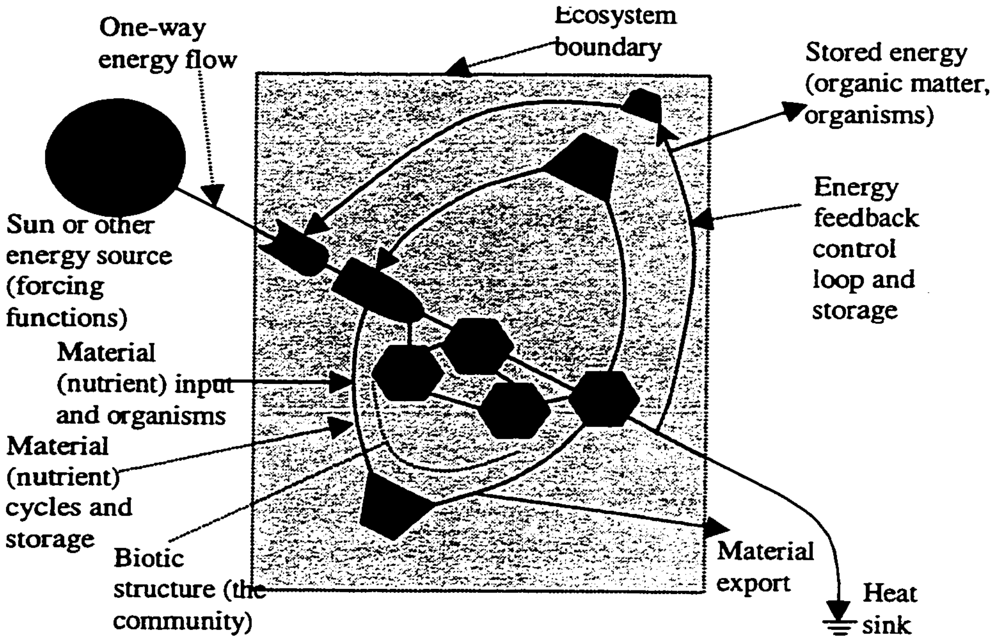


Figure 3-4. Ecosystem Model, with Emphasis on Energy Flow, Material Cycles, and Storage (S), and Food Webs Comprising Autotrophs (A) and Heterotrophs (H) [after Odum, 1997]

Such models have seen limited exposure beyond theoretical application to limited scenarios, and none were identified with current analytical or numerical implementations.

3.3. Governing Principles and Equations

The primary principles and equations that underlie the major classes of models need elucidation. This is done in the following sections by category.

3.3.1. Surface/Subsurface Hydrology

In considering the water balance within a watershed, integrated models must acknowledge the impact of humans through use of the General Quantitative Water Resources Balance Equation [after Miloradov et al., 1995] over simple water balance equations. This equation considers multiple use of a given volume of water, leading to the expression below:

$$\sum_{g=1}^{G}(\Delta V)_g = \sum_{a=1}^{A}(\Delta V_{\mathrm{in}})_a + \sum_{b=1}^{B}(\Delta V_{\mathrm{out}})_b + \sum_{c=1}^{C}(\Delta V_{\mathrm{dis}})_c + \sum_{d=1}^{D}(\Delta V_{\mathrm{w}})_d - \left[\sum_{e=1}^{E}(\Delta V_{\mathrm{E}})_e + \sum_{f=1}^{F}(\Delta V_{\mathrm{ET}})_f\right] \quad (1)$$

where

$\sum_{g=1}^{G}(\Delta V)_g$ = total change in the volume of water in a given volume over a given time

$\sum_{a=1}^{A}(\Delta V_{\mathrm{in}})_a$ = total surface or ground water inflow

$\sum_{b=1}^{B}(\Delta V_{\mathrm{out}})_b$ = outflow lost to deep aquifer

$\sum_{c=1}^{C}(\Delta V_{\mathrm{dis}})_c$ = flows into surface water bodies due to user discharges

$\sum_{d=1}^{D}(\Delta V_{\mathrm{w}})_d$ = withdrawals from surface or ground waters by users

$\sum_{e=1}^{E}(\Delta V_{\mathrm{E}})_e + \sum_{f=1}^{F}(\Delta V_{\mathrm{ET}})_f$ = sum of direct and terrestrial/aquatic vegetation evapotranspiration losses

Management of surface waters also requires analysis of surface flows and elevations. These types of simulations generally rely on use of the one-dimensional energy equation or the momentum equation for situations where the water surface profile is rapidly varied [HEC, 1998a]. For subsurface problems, general approaches can use the Laplace equation for flow in unconfined aquifers considered homogeneous and isotropic. Solution can be difficult, so approximations are made such as assuming flow is horizontal and uniform. By equating net outflow to the negative rate of change of storage, the nonlinear Bousinessq equation is generated, as follows:

$$\frac{\partial}{\partial x_i}\left[h\frac{\partial h}{\partial x_j}\right]+\frac{\partial}{\partial y_i}\left[h\frac{\partial h}{\partial y_j}\right]=\frac{S}{K}\frac{\partial h}{\partial t} \tag{2}$$

where

h = mean aquifer water level (L)

S = apparent specific yield

K = hydraulic conductivity (L/T)

Use of the above expression within a model grid will require input of initial and boundary conditions giving either initial head distribution or lateral boundary conditions (fixed head or fixed flux). Ground water flow velocity determinations make use of Darcy's Law as follows [Singh, 1992]:

$$Q = qA = -KA\frac{dh}{x_j} \tag{3}$$

where

h = piezometric head (L) = Z + p/ρg with p = pressure ($ML^{-1}T^{-2}$) and ρg = specific weight ($ML^{-2}T^{-2}$)

q = specific discharge (Q/A) or velocity (LT^{-1})

Z = static head above given datum (L)

Some recent examples of modelling using the MODFLOW model with modifications may serve to demonstrate use of the above expressions [Restrepo et al., 1998; Jones, 1997].

The modelling of rainfall/runoff is also frequently required, and can be accomplished with such tools as HEC-HMS [HEC, 1998b] or the Environment Canada CFS toolset.

3.3.2. Surface/Subsurface Water Quality

In considering the water quality within a watershed, surface waters are often modelled using the dissolved-oxygen sag (Streeter–Phelps) equation, as follows [Droste, 1997]:

$$D = \frac{k_1 L_0}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_0 e^{-k_2 t} \tag{4}$$

where

D_0 = initial dissolved-oxygen deficit (mg/L) k_1 = BOD exertion coefficient (d^{-1})

k_2 = reaeration coefficient (d^{-1}) L_0 = initial ultimate BOD (mg/L)

If the expression is expanded to include the effects of nitrification and sediment oxygen demand (SOD), then it becomes [Gore and Storrie, 1992]:

$$D = \frac{k_1 L_0}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_0 e^{-k_2 t} + \frac{3.76 k_N N_0}{k_2 - k_N}\left(e^{-k_N t} - e^{-k_2 t}\right) + \frac{s}{k_2}\left(1 - e^{-k_2 t}\right) \tag{5}$$

where

k_N = rate of nitrification (d^{-1}) N_0 = initial value of NH_{3T} (mg/L)

s = rate of SOD (mg/L/d) = k_s/d where k_s = areal SOD rate(g/m^2/d), d = depth (m)

This expression is again expanded in QUAL2E to include such factors as algae production, the phosphorus cycle, particulate settling, dam reaeration and photosynthesis [EPA, 1987]. Shortcomings in surface water quality modelling using approaches like QUAL2E have been identified, particularly with respect to the influence of non-point sources (NPS). Studies have therefore sought to produce NPS generation terms, such as nutrient generation rates as a function of land use in the Catchment Management Support System [Young et al., 1995]. Other modelling approaches involve use of policy criteria such as percentile limits or alternatives such as uniform discharge quality control systems or water quality objective systems [Matthews, 1995; MOEE, 1995], and cadastre systems (inventory system) [Marjanovic, 1995]. Within the WASP5 water quality model NPS loading may be estimated using the EUTRO module [Warwick et al., 1997].

3.3.3. Socioeconomic Modelling

On the economic side models are used to examine relationships between the economic concept of value and biophysical dimension of the protected area [Kramer et al., 1995; Onal et al., 1998]. Management models or policy model frameworks seek to provide guidelines to follow for management decisions that concern natural resources, for example, the model developed to guide decisions on rice production development policy and natural resource management policy in the Senegal River Basin [Venema, 1993]. The integrated nature of a WMDSS requires inclusion of models such as these. Efforts at producing such models to date have resulted in site and situation specific products with little potential for generalisation. This is an area requiring significant future effort.

3.4. Indices and GIS

The concept of trophic states for water bodies has been used for decades. Simply stated, the concentration and loading of nutrients directly influence the trophic state, such that as levels rise total biomass increases while species diversity decreases [Droste, 1997]. Species types and diversity indices can therefore serve as an indicator of the trophic level. While there is no question that chemical criteria and toxicological studies serve vital roles in assessing and controlling water quality, consensus is emerging that threats to water bodies come not from a single toxicant, but from an array of stresses including changes to flows, channel modifications, sedimentation, excesses in nutrient inputs, etc. [Perry and Vanderklein, 1996]. This was clearly demonstrated in Ohio, where the proportion of waters assessed as degraded by chemical criteria was 50% lower than the proportion assessed when biological assessments were used instead [Karr, 1995].

Early bioassessments have today grown into complex indices. Some examples of indices in use are as follows [after Perry and Vanderklein, 1996]:

1. <u>Saprobic Index</u>. A weighted numeric index is used to calculate pollution stress, with organisms in the various saprobic zones (these zones refer to areas of a stream below a pollution source showing particular levels of stress) being assigned an according

number. This is multiplied by an abundance value, and the overall weighted average indicated the level of pollution.

2. Percent EPT. This index measures the percent of collected organisms coming from the orders Ephemeroptera, Plecoptera and Trichoptera, these orders all being plentiful in cold high-quality waters and sensitive to pollution.

3. Diversity Index. This type of index relies on assessment of the relative abundance of several taxa. Impacted systems show less diversity than unimpacted ones.

4. Biotic Index. This type is similar to the diversity index, but relies on a restricted group of organisms – those found in the benthos.

5. Integrated or Multiple Index. To overcome the shortcomings of the above indices, integrated measures have been developed such as the popular Index of Biotic Integrity [Karr, 1981], which uses the abundance, trophic composition, species composition and condition of fish through a range of ecological levels (individual through community to ecosystem). A similar Rapid Bioassessment Protocol consisting of eight metrics gathered from two different stream habitats has been developed by the US EPA.

Indices have seen widespread use in the assessment of river health, and have the potential to be valuable components of a watershed management system. They can be tailored to suit the elements of greatest concern for a particular situation – the only danger in doing so being that customisation erodes the comparability of the index to other systems. Some work has sought to overcome site specificity through development of watershed scale indices of biotic integrity that use whole watershed variables for metrics rather than site specific variables, such as the work of Moyle and Randall [1998] in California. This work saw development of a Watershed-Index of Biotic Integrity (W-IBI) that takes into account native fish assemblages, abundance of native frogs, presence of anadromous fish and the introduction of trout into previously fishless streams.

Another tool that lies outside the sphere of modelling but inside the sphere of environmental decision support systems is geographic information systems, or GIS. A

GIS offers the most comprehensive and powerful landscape characteristics database available. Landscapes are divided into themes such as soils, geology, vegetation, elevation, etc., in essence, a GIS acts as a computer-assisted system for the capture, storage, retrieval, analysis and display of spatially referenced data [Arnoff, 1991]. A GIS by definition then is extremely data intensive, which is often the limiting factor in its application – as is also the case with many modelling tools. Widespread attention has recently been paid to the integration of GIS into DSS and other land management efforts. Indeed, such uses figure prominently in the marketing of GIS, many of which come with scripting languages permitting their customisation for such uses. Cost can be prohibitive, however, as can be the level of expertise required to use the product. Examples of commercial GIS packages include ArcView, Arc/Info and Grassland. A GIS offers a powerful land use data input function to any watershed management system. Efforts to produce GIS-based DSS have been somewhat successful [Watson and Wadsworth, 1996; Montas and Madramootoo, 1992; Zhou, 1998]. A recent example is the Dee Catchment Management Planning Geographic Information System effort in Scotland [Webb and Bacon, 1999]. This project saw an Arc/Info Unix-based GIS database used as a framework for multi-user efforts to manage the Dee watershed for Atlantic salmon production. While highly successful at meeting this mandate, the system saw limited value as an engine for running the management decision process, due to the lack of accompanying modelling tools. Indeed, because the key parameter, channel width, was not provided by the GIS data, a separate survey and analysis was required to produce the accessibility index. The scale of the dataset necessary to cover the complete catchment was such that fine measurement of channel width was not possible from the data. Access to a modelling toolset is the defining characteristic of a DSS – without that, one is left simply with an aid to data visualisation. This is the principle reason why a WMDSS would most likely need development as a stand alone application, with the option for GIS import/export capabilities. In this way, the development can be directly influenced by the data requirements of the modelling tools. It is anticipated that further development of GIS will lead to a point where they become the tool of choice to form the basis of a WMDSS.

3.5. *Decision Support*

The implementation of automated decision support systems has seen widespread application in business management for years. The last decade has seen a spillover into environmental management. Development of DSS hinges on uncovering the decisions which need supporting, and on the process through which the decisions are made. For environmental systems and watershed applications in particular, DSS are often a component of or associated with management tools. Decisions form part of the management process. Management runs on information – the applicability of IT support to such a process is clear.

The critical abilities of decision-making systems are as follows [Lein, 1997]:

1. Ability to collect information,
2. Ability to formulate models,
3. Ability to govern problems,
4. Ability to analyse problems,
5. Ability to evaluate problems, and
6. Ability to implement strategy.

A decision-making system can be viewed as a person vested with the responsibility to make a decision coupled to a DSS – hence, the DSS must support or assist in some or all of the seven critical abilities listed above. A classification scheme has been developed for decision problems suited to DSS automation, as detailed in Table 3-2. It can be seen that many of the problems facing watershed users and planners fit into the types defined in Table 3-2. If the task of a DSS is generalised, it can be said that such a system must be designed to support the solution of ill-structured problems – it must furnish its users with a powerful problem solving environment incorporating models directly into its design. The fact that problems will be ill-structured means that each problem solving scenario will bring with it unique characteristics. A start to finish support system will be impractical, in that it would end up being too specific for subsequent use with problems bringing with them new factors. All scenarios will require access to some defining functional blocks, however. By looking at these, an architecture supporting a system useful with ill-structured problems emerges. This generalised concept has been broken into functional blocks by Sage [1991], as shown in Figure 3-5.

Problem Class	Task Definition
Type O	mechanistic; non-thought-provoking; compliance with limited alternatives; singular objectives; few complications
Type A	use of computer as visual aid; data sorting and data search; automation of routine computations
Type B	issues related to tradeoffs; problems with conflicting objectives
Type C	structural complexity; large in size and scope; difficult to visualise
Type D	complex; dynamic; highly qualitative

Table 3-2. Classification of Problems Suited to DSS Automation [after Davis, 1988]

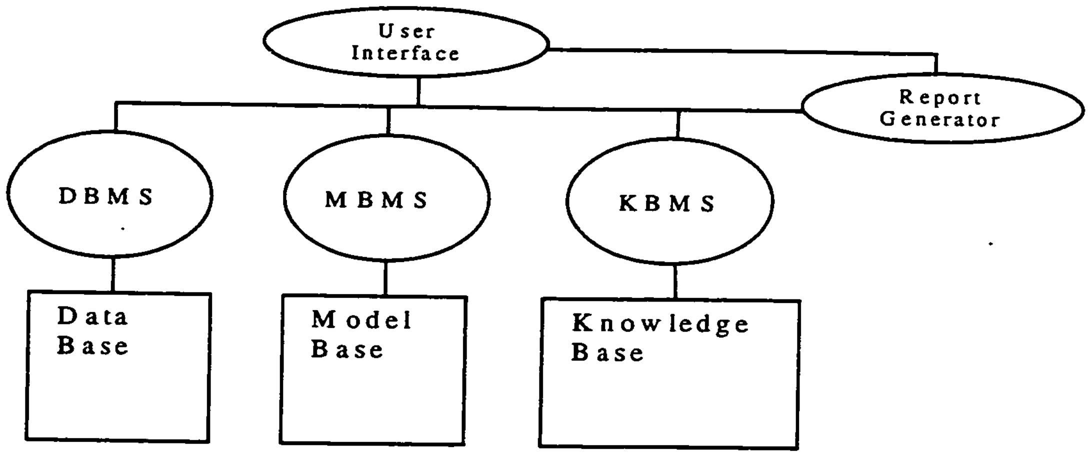


Figure 3-5. Critical Components of DSS [after Sage, 1991]

For the design of a watershed management DSS, it will also be important to incorporate the functionality associated with the management process: access to relevant reference information, and support for integrated views of the watershed, will be key.

3.6. *Integration*

The emerging science of integration in watershed management is receiving ever greater attention, as it is realised that integration is essential to the generation of comprehensive management strategies. The Final Report of the WPI Science and Technology Task Group [STTG, 1997] in Ontario made significant reference to the critical link of integration in watershed management. The definition for integration given was in realisation of the "need to understand the interrelationships of the physical, biological and chemical components of [the] watershed through integration of information across disciplines." This is accomplished through taking a systems view of the watershed (hence the systems engineering methodology adopted for this project) and using an integrative approach to watershed planing with a number of discrete steps:

1. overview the system,
2. define the structure, the affective linkages of the system, and key components to be studied,
3. reduce the system to its constituent components for the purpose of scientific study,
4. study the component parts,
5. reaggregate the system, and
6. re-evaluate the overview focusing on interrelationships and the whole system.

The WMDSS tool must support the above approach, with support for all constituent component parts of the system.

3.7. *Software Modelling Approaches*

There are several software modelling approaches appropriate for design of the WMDSS. The approach chosen must support the system engineering methodology previously outlined and must provide the flexibility to interface with legacy software from the 'procedural' days of programming without preventing use of more advanced Object-

Oriented (OO) design paradigms. Once the design approach is chosen, an appropriate language must then be selected.

Conceptualisation of a watershed naturally supports an OO approach. Indeed, to the greatest degree the actual watershed with its physical characteristics should be represented in code – program structure then becomes the defining of interrelationships between objects, supporting the need for an integrated watershed view completely. Such a pure OO approach, while conceptually elegant, imposes constraints on formulation of the management side of the software, however. An event-based paradigm to fully support inclusion of the 'manager-in-the-loop' is necessary. The explanation of the following paragraphs will make this point more clear.

One comprehensive OO approach is the Coad, Yourdon and Nicola OO Analysis (OOA), OO Design (OOD) and OO Programming (OOP) method, as follows [Coad and Nicola, 1993]:

1. OOA. Works with problem domain classes and objects.

2. OOD. Focuses on human interaction, task management and data management classes and objects.

3. OOP. Provides implementation strategies for implementing OOA and OOD results.

The method provides a number of principles in support of the above components, key among them being methods of organisation (object classification or hierarchy establishment), categorisation of behaviour (what do objects do?) and personification (what are an objects characteristics?). Objects are defined as instances of their object class (a class is in essence a template) that perform a defined set of services. Objects act as both senders and receivers of information to/from other objects.

The method uses an architecture consisting of four major components: the human interaction component (HIC), the problem domain component (PDC), the task management component (TMC) and the data management component (DMC). This architecture exhibits marked similarities to the Decision Support sub-systems of a DSS

(Figure 3-5) – HIC=GUI, DMC=DBMS, TMC=MBMS, PDC=KBMS. In fact, both of these architectures represent logical groupings of functionality that necessarily bridge between the conceptual framework of the functional allocation phase of systems engineering and its implementation in software. OOA/D/P is nothing more than a subset of systems engineering appropriate for use in defining complex systems.

While the physical domain of the WMDSS (the watershed) can easily be thought about in terms of a collection of objects of various types, it is more difficult to include the user and the user's problem space within that domain. The user will ask the system to do certain things to or with the objects defining the watershed being managed. This suggests that a design philosophy that couples the robustness of the OO approach for the physical domain to the flexibility of the event approach for the user interaction domain is best.

Selection of language must therefore expand from pure OO languages such as Smalltalk to mainstream tools such as C++, Delphi version 2.0 or later and Visual Basic version 5.0 or later (the absence of a Web-focused requirement precludes such languages as Java, which while offering platform independence carries a significant speed of operations handicap). All three of these languages offer support for OOA and OOD in the versions listed along with their legacy abilities to code procedural or event based programs. All also offer Integrated Development Environments (IDEs - more commonly called Visual versions) for form design. While any of these three would have made a good choice, the increasingly widespread use of Visual Basic for rapid application prototyping (and the suggestion at the GIS development company ESRI that Visual Basic would become the scripting language of choice for future versions of ArcView) led to selection of Visual Basic for this project.

A final step in defining the software modelling approach is integration with the systems engineering methodology. This has been accomplished by placing the OOA and OOD phases within the Map Requirements to Functions and Synthesize Functions steps. Adoption of an OO approach for the physical domain of the WMDSS necessitates production of an Object Model (in keeping with good systems engineering methodology).

3.8. *Government Bodies and Agencies*

An important part of establishing the non-physical inputs to the watershed management problem space involves outlining the responsibilities of the various levels of government. The following list summarizes key points:

1. Federal Government

(a) Environment Canada

i. Responsibility. Leadership on matters of environmental concern, enforcement of federal regulations and national research at centres such as CCIW (NWRI).

ii. Legislation. Federal regulations such as the Canada Water Act and the Canadian Environmental Protection Act are shepparded, along with acts specific to international boundaries such as the International River Improvements Act, the Lac Seul Conservation Act and the Lake of the Woods Control Board Act.

(b) Department of Fisheries and Oceans

i. Responsibility. The DFO, on behalf of the Government of Canada, is responsible for policies and programs in support of Canada's economic, ecological and scientific interests in the oceans and freshwater fish habitat; for the conservation and sustained utilization of Canada's fisheries resources in marine and inland waters, and for safe, effective and environmentally sound marine services responsive to the needs of Canadians in a global economy.

ii. Legislation. Fisheries Act.

2. Provincial Government (Ontario).

(a) Ministry of Environment

i. Responsibility. Provide information, set policies and act as a centre of excellence on issues relating to the environment.

ii. Legislation. Key pieces of legislation are Provincial Water Quality Objectives, Environmental Protection Act (1990), Ministry of the Environment Act (1990) and the Ontario Water Resources Act (1990).

(b) Ministry of Natural Resources

i. Responsibility. Provide information, set policies and act as a centre of excellence on issues relating to natural resources.

ii. Legislation. Ministry of Natural Resources Act (1990), various mining and fossil fuel acts.

(c) Ministry of Agricultural, Food and Rural Affairs

i. Responsibility. Provide information, set policies and act as a centre of excellence on issues relating to agriculture, food and rural affairs. Under agriculture, responsibilities include standards for crop and livestock farming. For food affairs, there is a provincial inspection agency. The rural affairs section deals primarily with rural development.

ii. Legislation. Of note are the Agricultural and Horticultural Organisation Act (1990), the Crop Insurance Act (1990), the Livestock and Livestock Products Act (1990), and the Ministry of Agriculture and Food Act (1990).

(d) Ontario Conservation Authorities (CA)

i. Responsibility. The responsibility of a lawfully constituted CA is to establish and undertake a program designed to further the conservation, restoration, development and management of natural resources other than gas, oil, coal and minerals [CA Act, 1990].

ii. Legislation. CAs are constituted under the Conservation Authorities Act (1990).

3.9. *The Problem of Scale*

Throughout the previous sections the effects of geographical and temporal scale considerations are significant. The scale at which a watershed is viewed and assessed has a direct influence on the information obtained. The scale of the problems being addressed requires data and analysis at a similar scale, a requirement that is often difficult or impossible to meet. Recognising the relationship between scale and understanding is a theme that must run throughout the WMDSS system. This is further examined through reference to the variation of riparian vegetation across scales within a watershed.

Longer time scale changes are more appropriate to large area analysis, and vice-versa. Vegetation varies continuously and rapidly while landform variation is often episodic (e.g., extreme flood events) or relatively slow. Analysis of the linkage between morphological processes (process-response) and vegetation (continuous change) must consider the implications of scale. This is most acute in intermediary time scales between long term evolutionary changes and immediate extreme event changes – it is here where response and relaxation times of landforms and ecosystems may differ extremely [Huggett, 1991]. Table 3-3 exhibits typical examples of order of magnitude change rates for geomorphic and ecological phenomena. From it one can see that the establishment of a complete vegetation cover after a change in land use or an extreme event is important due to the fundamental relationship between erosion and vegetation cover. Comparison of the scale of the forcing event and the recovery event of concern permits assessment of the applicability of the comparison, and offers an explanation of the potential lack of correlation at the analysis scales used. It would not make sense, for instance, to look for the same vegetation response to a logging event as to a change in sea level.

Landscape Phenomenon	Rate	Response Time	Relaxation Time	Time scale
Development of incipient soil cover	10^{-1}-10^{0}	10^{0}	10^{1}-10^{2}	10^{0}-10^{1}
Development of mature regolith	10^{-5}-10^{-3}	10^{0}-10^{2}	10^{4}-10^{5}	10^{0}-10^{4}
Landscape dissection	10^{-8}-10^{-6}	10^{0}-10^{2}	10^{2}-10^{5}	10^{0}-10^{4}

Landscape aggradation (regional fill)	10^{-7}-10^{-5}	10^{0}-10^{2}	10^{1}-10^{4}	10^{0}-10^{4}
Fluvial erosion/sedimentation	10^{-2}-10^{1}	10^{-3}-10^{0}	10^{0}-10^{2}	10^{-1}-10^{2}
Aeolian erosion/sedimentation	10^{-2}-10^{1}	10^{-3}-10^{0}	10^{-2}-10^{0}	10^{-3}-10^{0}
Establishment of complete vegetation cover	10^{-1}-10^{1}	10^{-1}-10^{0}	10^{0}-10^{1}	10^{-1}-10^{1}
Secondary succession	10^{-2}-10^{0}	10^{0}	10^{1}-10^{2}	10^{0}-10^{1}
Primary succession	10^{-3}-10^{0}	10^{0}-10^{1}	10^{1}-10^{2}	10^{0}-10^{1}
Vegetation composition change	10^{-1}-10^{1}	10^{-1}-10^{1}	10^{0}-10^{1}	10^{-1}-10^{1}

Table 3-3. Typical order of magnitude rates, response times and time scales for geographic and ecological phenomena on uplands of the North Carolina Coastal Plain (all values in years except rates)[after Phillips, 1993].

Relating the above information to alluvial flood plains, examination of scale can answer the question of whether or not alluvial sedimentation can be considered independently of vegetation. From Table 3-3, it can be seen that vegetation changes occur over scales of 10^{-1} years to decades while fluvial erosion and deposition occur over time scales of 10^{-1} years to centuries – there is therefore generally a significant difference in time scales, such that the two can be considered independent in the majority of cases. In another example, identification of scale explains how upland surfaces in the North Carolina Coastal Plain can be classed both as remarkably stable (over geologic time – [Daniels et al., 1971]) and highly variable (over decades – [Phillips, 1993]).

The extreme very short time scale event such as a high gradient river flood should therefore best be paired to rapid vegetation effects and adjustments for causal relationships. An example of such a situation is the 900 year flood on Plum Creek in Colorado in 1965. The flood caused extensive channel widening, left large sediment deposits and wasted major stretches of terrace banks with their accompanying vegetation [Hupp and Osterkamp, 1996]. Over 50% of the pre-flood trees and shrubs were destroyed during the flood; in the years since, woody plants have established themselves on islands, stable bars and developing flood plains. A study of the flood highlights the fact that the numerous islands in the channel came about under two main mechanisms: firstly, through accretion downstream from woody snags, and secondly, by stagnation around a previously moving bar for long enough to allow colonization by woody species. In-stream vegetation jams have often been identified as a major factor in high gradient stream morphology. Flood plains grow out of accreting bar surfaces, and remain if vegetation becomes succiciently well established prior to another extreme event occurring.

Scale considerations must be kept in mind in a decision-making process. Support measures for keeping track of changes to 'snap-shot' steady-state analyses of the watershed must be included within WMDSS, either functionally or procedurally in its application. On physical scales, available dataset scales may well drive the scale at which analysis can be conducted. The finctionality identified under the time-series analysis heading will be useful in creating summaries of datasets (metadata). These metadata can be compared over timescales longer than the scales used for immediate analysis to keep a record of long term changes.

Chapter 4. Final Problem Definition

This phase calls for validations of the information in Initial Problem Definition followed by the key steps of requirements capture, functional allocation and data model production.

4.1. Systems Engineering Methodology, Systems View of Problem Space, Process Inputs to Water Resource Management

Previous content is confirmed. The cornerstone of Phase 1 was to carry out a comprehensive requirements capturing from water resource management groups, both from an engineering consulting perspective and a government agency perspective. To this end, 50 user surveys were mailed to target groups in mid-October 1998. The mail out sought to get confirmation on the requirements uncovered in background research, and to solicit user feedback on the ongoing design effort. Target groups consisted of engineering consulting firms (33), provincial/regional/municipal government bodies (9), and Conservation Authorities (8) all from Eastern Ontario. Returns received totalled seven, with three of these being from industry (Golder Associates, AJ Robinson & Associates, and XCG Consultants Ltd.) and four from government bodies (SNRCA, Rideau Valley CA, Lower Trent CA, and City of Brockville – grouped as CAs henceforth). Some additional CAs expressed interest in being kept abreast of the project (Moira River CA, Mississippi Valley CA, and Otonabee Region CA). Sections 4.1.1 to 4.1.6 detail a summary of the questions and responses. Scores for questions were calculated simply by determining the average score on a scale of 1 to 5 for both the industry group and the CA group.

4.1.1. Respondent Particulars

Do you work singly, or as part of a staff? typically part of staff

If part of a staff, how many are on the staff? 6-10

4.1.2. Water Resource Planning

Have you (or your organisation) ever participated in the production of a watershed management plan? y = 6 n = 1

If so, what was your responsibility?

- production of hydrology characterisation
- coordination of overall plan
- water quality model development
- assessment of ground water and surface water interactions
- project director

If so, what IT tools (if any) did you use to assist you?

- GIS, including ARCView
- STORET database and conventional databases

Do you know of IT tools or models available for use in water resource planning?

y = 4 n = 3

If so, would you please describe them:

- RAISON management software from MOE
- no examples from other three 'y' responses

If you could design a decision support system for use in water resources planning, which of the following criteria would you consider important, and to what degree?

	Very ---- Not very
Criteria	1 2 3 4 5:Score (industry)(CAs)

- tools and information to support remediation measures planning (2.0)(2.0)

- tools and information to support water quality protection planning (1.3)(1.3)

- tools and information to support water quantity protection planning (1.7)(1.7)

- tools and information to support watershed analysis integration measures (2.3)(1.3)

- tools and information to support resource economic quantification analysis (2.3)(2.5)

Others? Please specify:

- integrate GIS/mapping with technical modules

- assess implementation costs

Comments on Section B:

- a key to water resource planning is having centralised access to information

4.1.3. Water Resource Decision Making

Have you (or your organisation) ever participated in a water resources decision making process (e.g., determining changes to point source outfall levels, determining flow adjustment/allocation between users, etc.)? y = 4 n = 3

If so, what was your responsibility?

- assessment of in stream (or in lake) water quality impacts (what if?)

- rendering recommendations to counties/Ministry of Municipal Affairs

If so, what IT tools (if any) did you use to assist you?

- water quality models

Do you know of IT tools or models available for use in water resource decision making?

y = 1 n = 6

If so, would you please describe them:

- nil

If you could design a decision support system for use in water resources decision making, which of the following criteria would you consider important, and to what degree?

Very -------- Not very

Criteria 1 2 3 4 5:Score (industry)(CAs)

- tools and information to allocate water withdrawals fairly amongst users (1.7)(3.7)

- tools and information to project the impact of new withdrawals on existing users (1.0)(3.7)

- tools and information to assess the impact of changes to rainfall/ runoff inputs (1.7)(1.3)

- tools and information to assess the impact of changes in ground water flows/levels (1.3)(1.3)

- tools and information to support cost-based comparisons (1.7)(2.3)

Others? Please specify:

- tools to support integration measures

Comments on Section C:

- nil

4.1.4. Physical Modelling/Analysis Tools

List the physical modelling/analysis tools that you have used (e.g., HEC, OTTHYMO, AGNPS), along with their particulars:

Model Name	Purpose	Source	Utility
WASP5	Water quality	EPA	useful, pre- and post-processor developed in-house
QUAL2E	Water quality	EPA	high
HEC2	Planning	US Army Corps of Engrs, HAESTAD	high
XP-SWMM	Water quality	XP Software	high
MODLFOW	Ground water quantity	USGS	high
SIMLAS	Water quality	SWFWMD	high
QUALHYMO	Water quality		high
OTTHYMO	Water quantity	J.F. Sabourin Assoc., Hull	high
MIDUSS	Water quantity		high
AGNPS	Water quality		poor
HEC-RAS			high

Table 4-1. Requirements Capture Mail Out Model Use Response

Are there physical phenomena (e.g., runoff, ground water flow) which you would like to be able to model but currently cannot? y = 3 n = 4

If so, please describe:

- ground water flow

- ground water contribution to baseflow

- detailed runoff modelling

- non-point source water quality modelling (e.g., phosphorus)

- erosion/sedimentation

- ground water quality

- fluvial geomorphology

Do you employ GIS in your water resource work? y = 6 n = 1

If so, how, and what package are you using?

- packages: ARCView, ARCInfo, AutoCAD, Ontario Base Maps, Intergraph MGE, Microstation, MapInfo

- tasks: buffering, overlay comparisons, mapping natural hazards, mapping natural heritage features, mapping setbacks, doing area calculations

Comments on Section D:

- nil

4.1.5. General Comments

- 'one stop shop' for modelling and integration needs needed

- better integration of cost-effective GIS into modelling/planning tools would be most beneficial

4.1.6. Summary

As hoped, the needs of the industry user group and CA user group are very similar, such that a common software package can be built and marketed to both. It is instructive to identify the area of significant difference between the two groups. For the CA group, tools supporting integration measures in water resource planning rank as the most important, while for industry such tools fall after tools to support water quality and water quantity protection measures (which are the second and third most important for agencies). For water resource decision making, provisions to support assessment and adjudication of water withdrawals rank high for industry but low for CAs – this is understandable when recalling that the province is responsible for allocation of withdrawal permission, this responsibility not being under the purview of CAs.

4.2. Requirements Analysis

As previously stated, a proper requirements analysis necessitates taking the broad requirements and breaking them into their sub-requirements such that a functionality mapping can be done.

1 tools and information to support water quality protection planning

Tools:	Functions:
model water quality:	
rivers creeks/streams canals groundwater drinking water	
BOD ammonia nitrogen phosphorus toxics turbidity esthetics	calculate chemical constituent levels using field data
sedimentation	calculate sediment loads
protection:	
assessment comparison to PWQOs	compare calculated levels to standards
planning:	calculate chemical constituent levels using input data
what-if analysis	

tools and information to support water quanity protection planning

Tools:	Functions:
model water quantity:	
rivers creeks/streams canals groundwater drinking water	
flows & surface elev's:	calculate surface flows & elev's using field data
annual seasonal daily trends variations	calculate groundwater flows using field data
inputs:	read in point source data enter data into database ask for needed data spatially reference data
rainfall runoff	
returns groundwater inflows surface inflows	read in areal data enter data into database ask for needed data spatially reference data
outputs:	
evapotranspiration	as for inputs

reporting
visual representation
forecasting

generate level reports
generate graphical reports
calculate trends

runoff
surface outflows
groundwater outflows
withdrawals

tools and information to support water quality protection planning

Information:

measures of water quality:

rivers
creeks/streams
canals
groundwater

drinking water

point sources:

location
C of As
operating rules
outfalls

read in point source data
enter data into database
ask for needed data
spatially reference data

non-point sources:

read in non-point source data
enter data into database

land use mapping
runoff

ask for needed data
spatially reference data
permit on-screen land use characterisation

meteorology:

rainfall
other precip.
evapotranspiration

read in met data
enter data into database
ask for needed data
spatially reference data

monitoring

display data time series identifying times of non-compliance

tools and information to support water quanity protection planning

protection:

assessment

compare calculated levels to standards/min. accept. flows

planning:

what-if analysis

reporting
visual representation
forecasting

calculate surface flows using input data
calculate groundwater flows using input data
generate flow reports
generate graphical reports
calculate trends

Information:

measures of water quantity:

rivers
creeks/streams
canals
groundwater
drinking water

as per inputs/outputs above

minimum acceptable flows:

rivers
creeks/streams
canals
groundwater

read in point source data
enter data into database
ask for needed data
spatially reference data

Table 4-2. Functional Allocation – Water Quality/Quantity

3 **tools and information to support watershed analysis integration measures**

Tools:

Functions:

ecological index:

IBI
RBP

calculate chosen index from field data

4 **tools and information to assess the impact of changes to rainfall/ runoff inputs**

Tools:

temporal comparisons:

rainfall
runoff

		infiltration
component linkages:		
between physical components between human/physical components	display cause/effect linkages between ecological components	remainder as per 2.
Information:		
botanic:	read in point source data enter data into database ask for needed data spatially reference data	
species diversity/species of interest/trends/structure		
geologic:	read in areal data enter data into database ask for needed data spatially reference data	
lithology structure		
human:	permit on-screen land characterisation by data type	
inhabitance (subset of land use)/ trends in populations culture economy/economic value of watershed elements land use/land use trends	calculate valuations calculate trends	
tools and information to support watershed analysis integration measures		
climatic:		
weather elements patterns precipitation levels/seasonal variations/trends		
zoologic:		
species diversity/species of interest/trends food webs patterns		
riparian zone:		
buffering		
geomorphology		

Table 4-3. Functional Allocation – Integration/Rainfall-Runoff

5 tools and information to assess the impact of changes in ground water flows/levels

Tools:

temporal comparisons:

- groundwater flows
- water table/aquifer levels

remainder as per 2.

6 tools and information to support remediation measures planning

Tools:

indexed search tool

Information:

damage assessments:

- rivers
- creeks/streams
- riverbanks
- wetlands
- water works
- riparian zones
- sedimentation
- surface water quality
- groundwater quality

remediation methods:

- stabilization
- treatment
- buffering

7 tools and information to project the impact of new withdrawals on existing users

covered under 2.

8 tools and information to support cost-based comparisons

Tools:

indexed search tool
costing/accounting tool

Information:

project cost data:

- historical
- comparison to similar
- budget/funding info

Table 4-4. Functional Allocation – Groundwater/Remediation/Withdrawals/Cost-based Comparisons

9	10	11
tools and information to support resource economic quantification analysis	tools and information to allocate water withdrawals fairly amongst users	assess implementation costs
Tools:	covered under 2.	covered under 8.
indexed search tool costing tool		
Information:		
resource cost data: fluvial land by type/use: agricultural forest urban rural wetlands buffer minerals recreation tourist migration area wildlife heritage		

Table 4-5. Functional Allocation - Economic Quantification/Withdrawal Allocation/Implementation Costs

Such a decomposition and allocation is provided in Tables 4-2-4-5. From the decomposition, the functions needed by the system are identified, ready for incorporation into the level 0 data model. Note that as sections are assessed, redundancies in functions emerge – a core set of functions covering all requirements emerges. These are placed on the data model within management system and GUI units.

4.3. Functional Analysis/Allocation and Synthesis

The level 0 data model represents the topmost level of the WMDSS system functional architecture. It brings together the individually identified functions from the decomposition into a system, allocated to the broad sub-systems previously identified. Each sub-system is further defined through the level 1 model. The following Figures 4-1 to 4-5 define the level 0 and 1 data models.

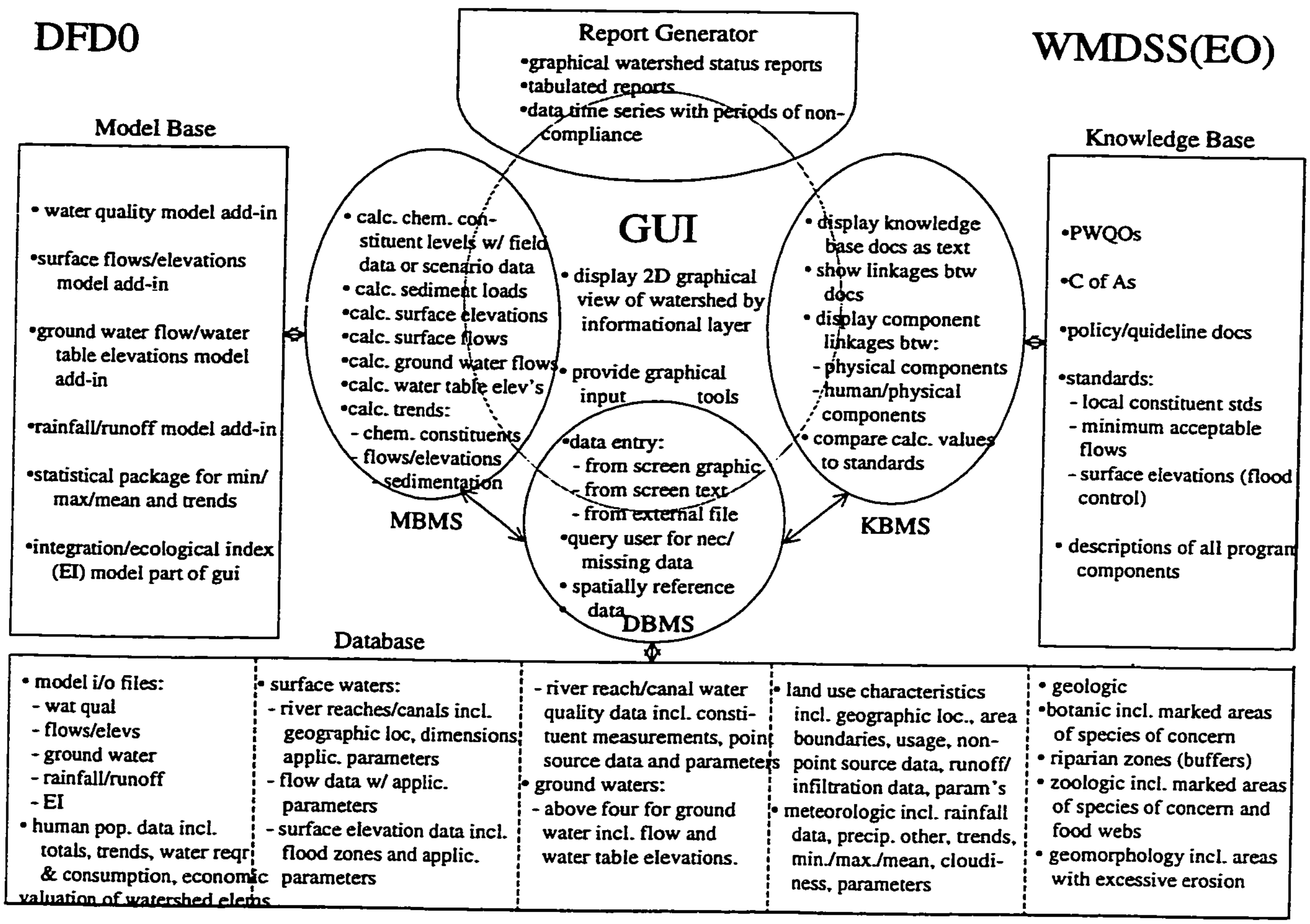


Figure 4-1. Level 0 Data Model

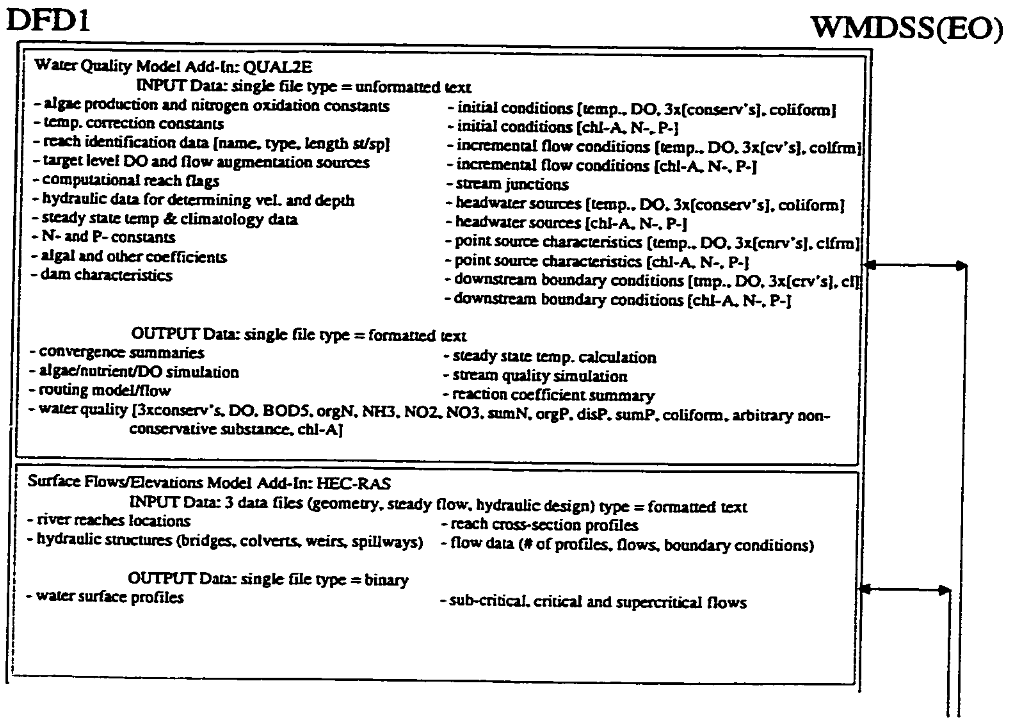


Figure 4-2. 1 of 4 Level 1 Data Model

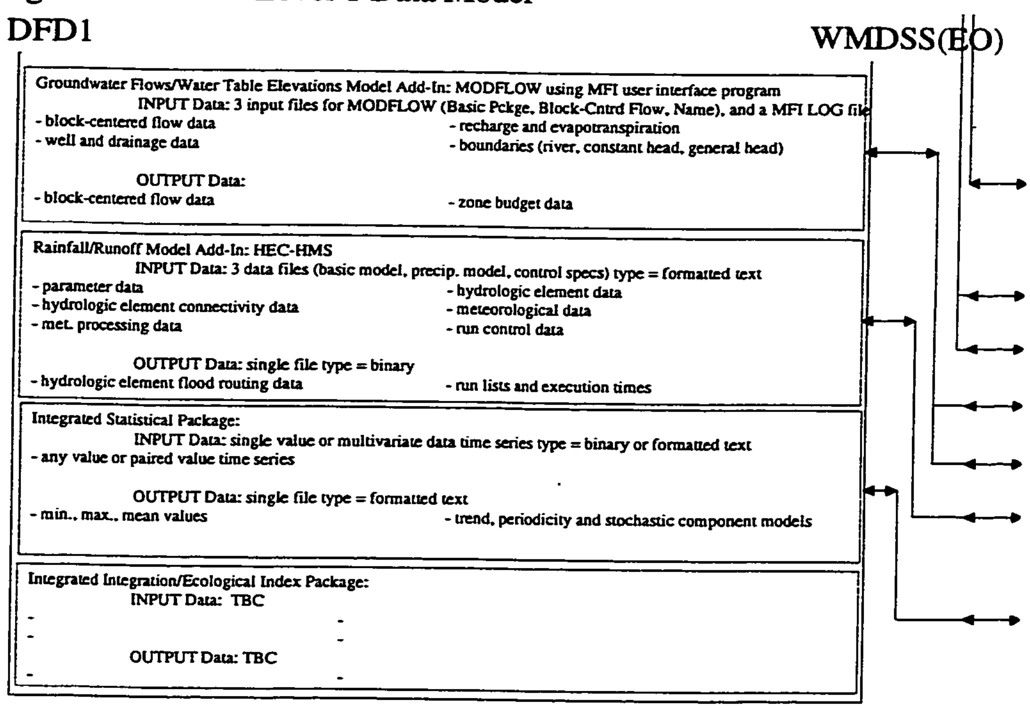


Figure 4-3. 2 of 4 Level 1 Data Model

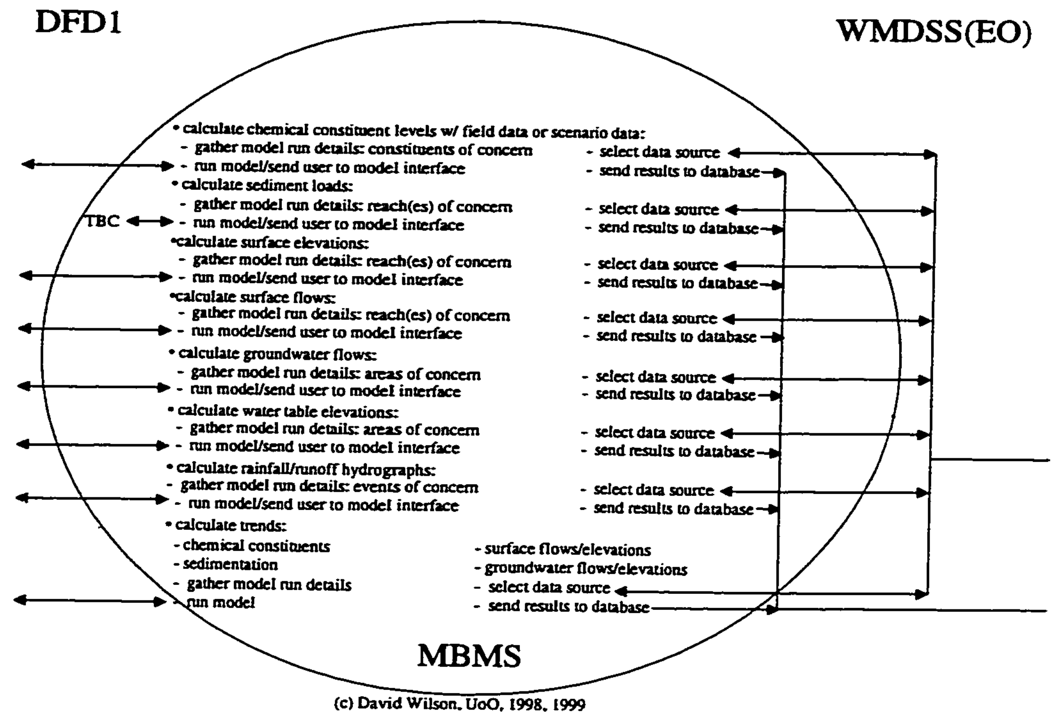


Figure 4-4. 3 of 4 Level 1 Data Model

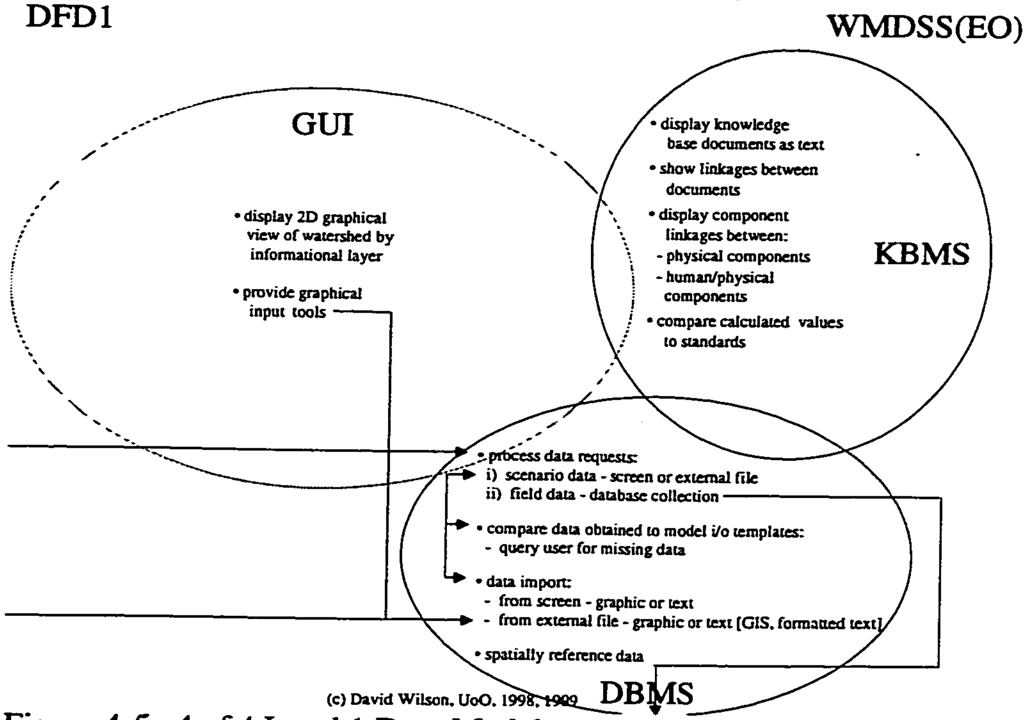


Figure 4-5. 4 of 4 Level 1 Data Model

4.4. Verification and Process Outputs

Verification is accomplished in Chapter 7 along with validation of the system. Process Outputs describe the decisions that are supported through use of the WMDSS system. Answering questions describing the needs of watershed stakeholders (as outlined previously in Section 2.4) constitutes a fairly comprehensive review of potential process outputs. Many of the needs cannot be addressed until the complete WMDSS system is functional. Within this study, the rendition of functionality to include support for water quality analysis partially satisfies the needs of government agencies and community groups for the protection and restoration of surface water quality.

Chapter 5. Object Model

Having mapped out the functional architecture for the WMDSS, the last task to complete prior to program design is to build the physical object model for the watershed elements that will underlay the application. As previously discussed, a combined event- and OO-based approach is being used. This section therefore details the object model for the physical watershed elements. The object model must describe the hierarchical relationships amongst the watershed objects, as well as defining their properties and methods.

In selecting the structure of the object model, it is also necessary to be aware of the structure used to define the data models of the physical tools to which the WMDSS will interface. A compromise between these (invariably) divergent models is required. Of principle concern are the primary water quality and surface flows/elevations model data formats (QUAL2E and HEC-RAS respectively). While basic structures are similar (use of headwaters, reaches, junctions), differences exist in the details (QUAL2E reach elements, called computational elements, must be of equal length, for example, while those in HEC-RAS do not have to be). Determination of the hydrologic element properties to capture must also keep a view towards the physical models – this is accomplished through reference to the data model completed in the previous section, where all pertinent tools have been characterised.

The first step then in producing the object model is to detail the object models for the physical models of concern. This has been accomplished in Figures 5-3 and 5-4, and is described in the following paragraphs:

1. QUAL2E

   (a) General. The version of QUAL2E used for this work is QUAL2E - The Enhanced Stream Water Quality Model, ID number: Software EPA-823-C-95-006, Documentation EPA-823-B-95-003 (Windows interface) and EPA 600-3-87-007 (DOS model) [EPA, 1987], which is applicable to well mixed, dendritic streams. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance (see Figure 5-1). It can predict up to 15 water quality constituent concentrations. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. By operating the model dynamically, the user can study diurnal dissolved oxygen variations and algal growth. However, the effects of dynamic forcing functions, such as headwater flows or point source loads, cannot be modeled with QUAL2E. QUAL2EU is an enhancement allowing users to perform three types of uncertainty analyses: sensitivity analysis, first-order error analysis, and Monte Carlo simulation. The purpose of the QUAL2E Windows interface is to make the model more user friendly. It provides input screens to facilitate preparing model inputs and executing the model. It also has help screens and provides graphical viewing of input data and model results.

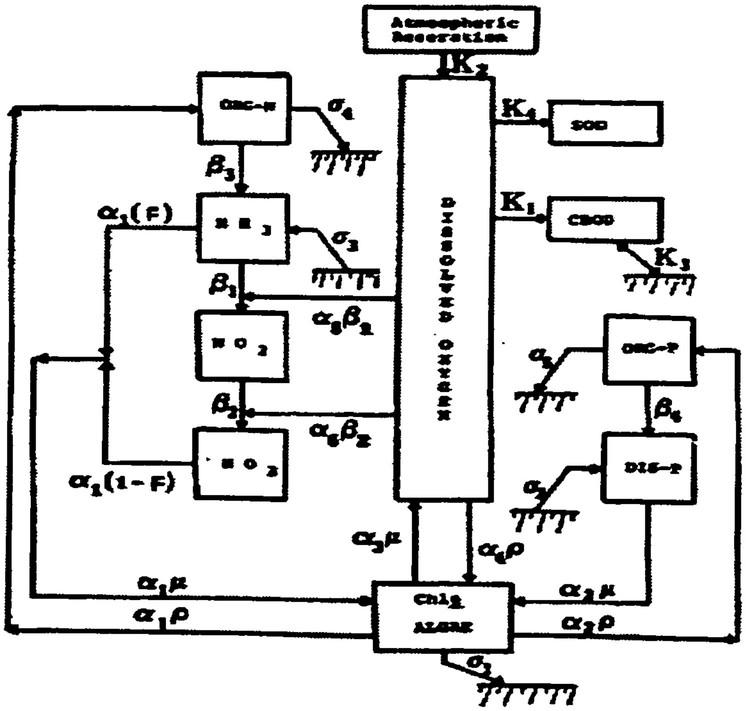
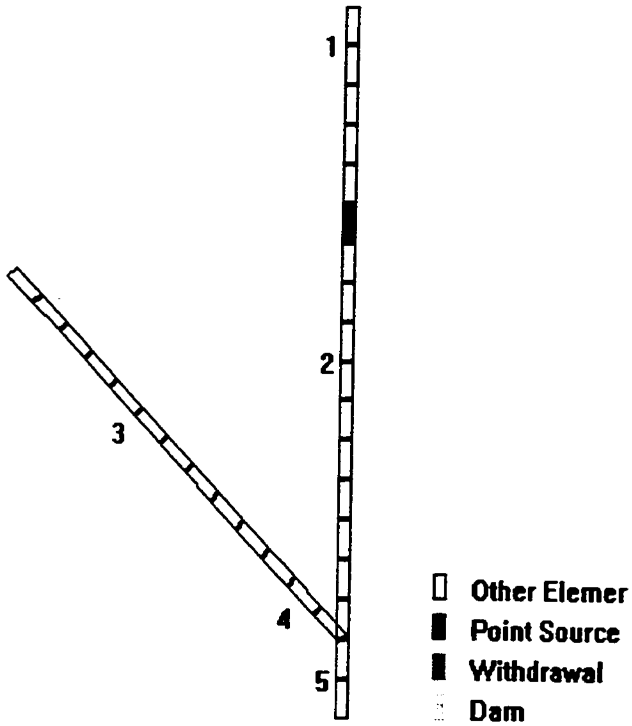


Figure 5-1. QUAL2E Constituent Relationships [after EPA, 1987]

(b) Object Model. The example in Figure 5-2 describes the QUAL2E object model.



QUAL2E breaks a river system down into headwater reaches and normal reaches. A reach is divided into equal length computational elements. Inputs to the system can only occur in a headwater element, in a point source element, or as incremental inflow allocated evenly along the elements of a reach. Confluences define junctions. Rate and temperature correction coefficients can be varied reach by reach, as can initial conditions and hydraulic parameters such as stage-discharge relationship coefficients.

Figure 5-2. QUAL2E Hydraulic Element Model Depiction

2. HEC-RAS

(a) General. HEC-RAS River Analysis System September 1998 version 2.2 was developed by the US Army Corps of Engineers at the Hydrologic Engineering Center in Davis, California [HEC, 1998a]. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The hydraulic analysis components consist of a steady flow water surface flow profile component used for calculating water surface profiles of steady gradually varying flow. It can handle a full network of channels, a dendritic system or a single river reach, and is capable of modelling subcritical, supercritical and mixed flow regime water surface profiles. The effects of various obstructions such as bridges, culverts, weirs and structures in the flood plain can be considered in the computations. The unsteady flow simulation component is capable of modelling one-dimensional unsteady flow through a full network of open channels. The final component designed for simulating one-dimensional sediment transport/movable boundary conditions (i.e., scour/deposition) is under development and soon to be available.

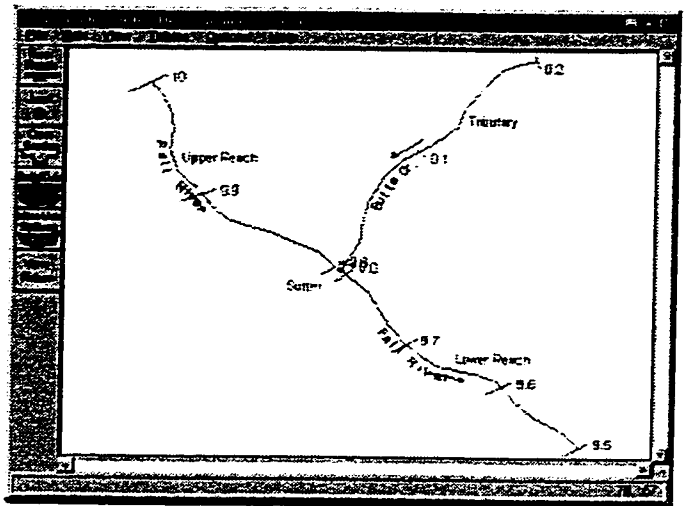


Figure 3.6 Geometric Data Window

Figure 5-3. HEC-RAS Geometric Input Screen Demonstrating Object Model [after HEC, 1998a]

(b) Object Model. Figure 5-2 helps describe the HEC-RAS object model. For HEC-RAS, rivers are also broken into reaches running from headwaters or junctions to junctions. Cross-sections are placed on the stream network wherever they are available, and define the cross-section from that point down to the next cross-section. The definition of a cross-section includes assignment of Manning roughness coefficients and contraction/expansion coefficients. Hydraulic structures are defined at their existing locations in much the same manner as cross-sections. Flows are assigned where known: depending on the regime being simulated (sub-critical, super critical or mixed flow), there is a minimum requirement to define either the start or end element flow.

The object models for the above models follow:

WMDSS(EO)

QUAL2E Object Model

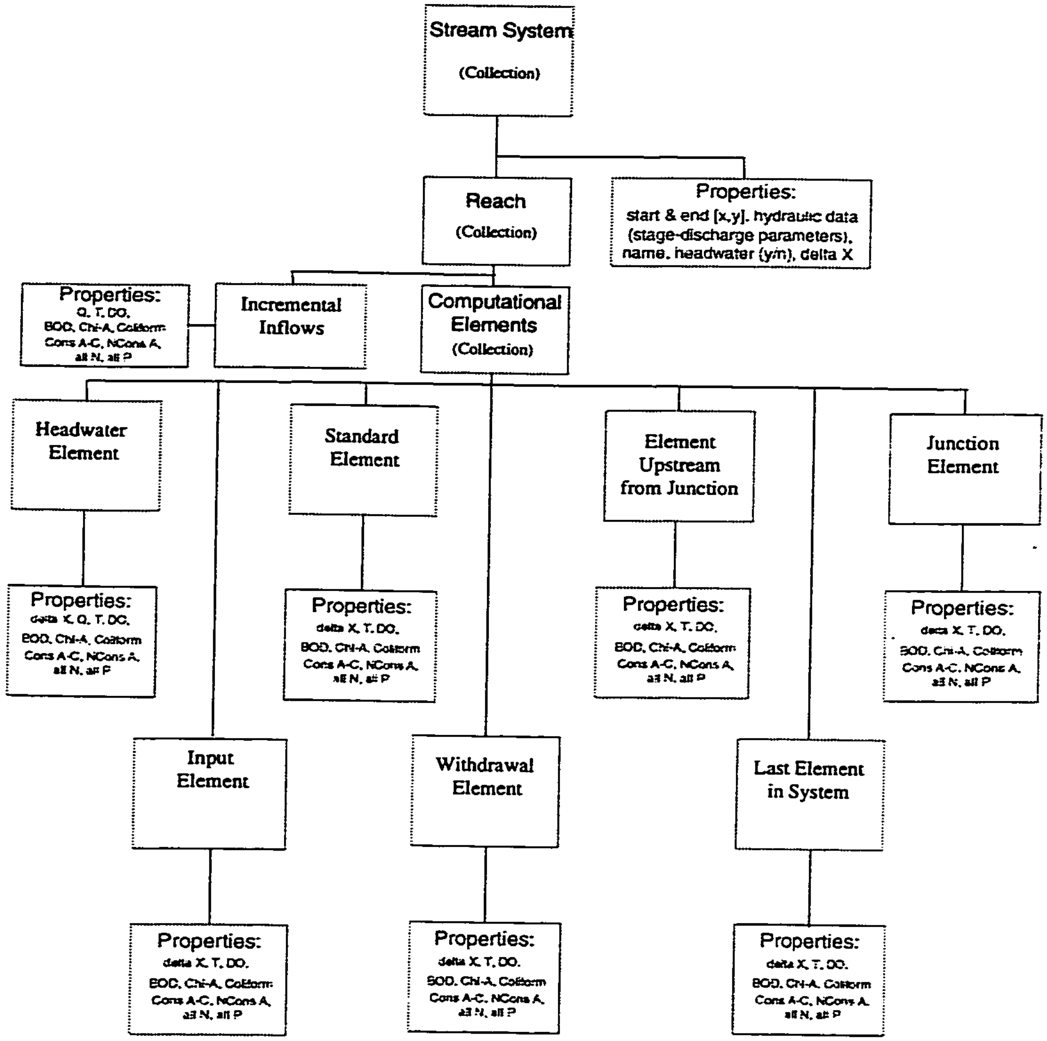


Figure 5-4. QUAL2E Object Model

HEC-RAS Object Model

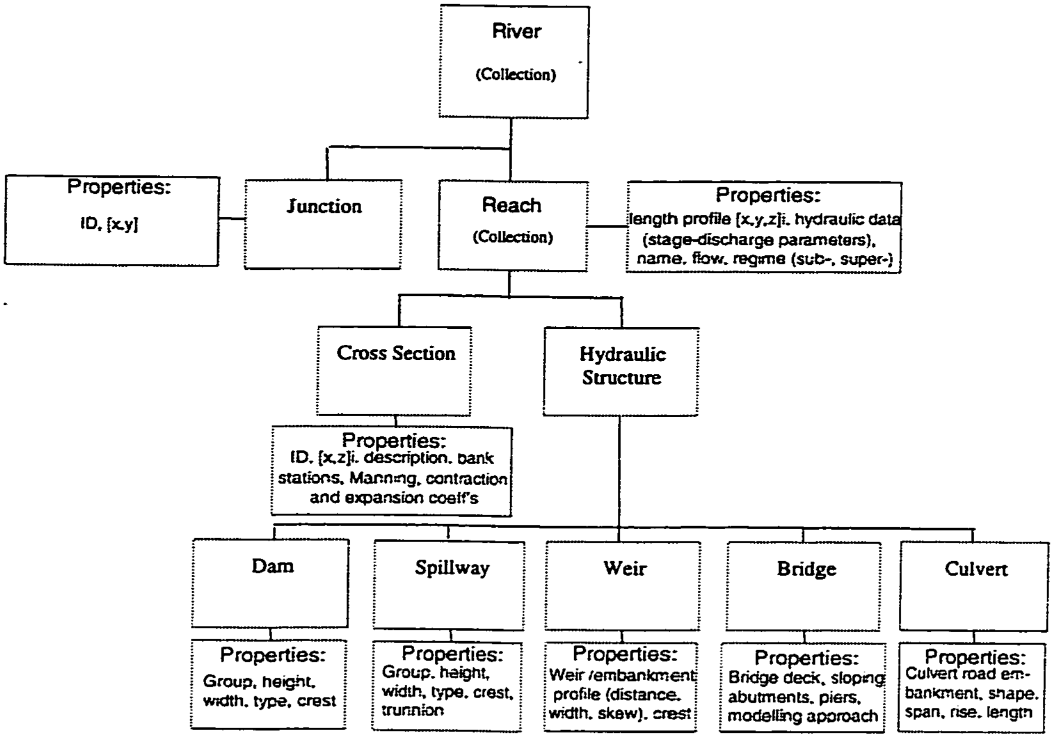


Figure 5-5. HEC-RAS Object Model

The WMDSS watershed object model is shown in the following Figures 5-5 to 5-8.

WMDSS Object Model: Hydrology

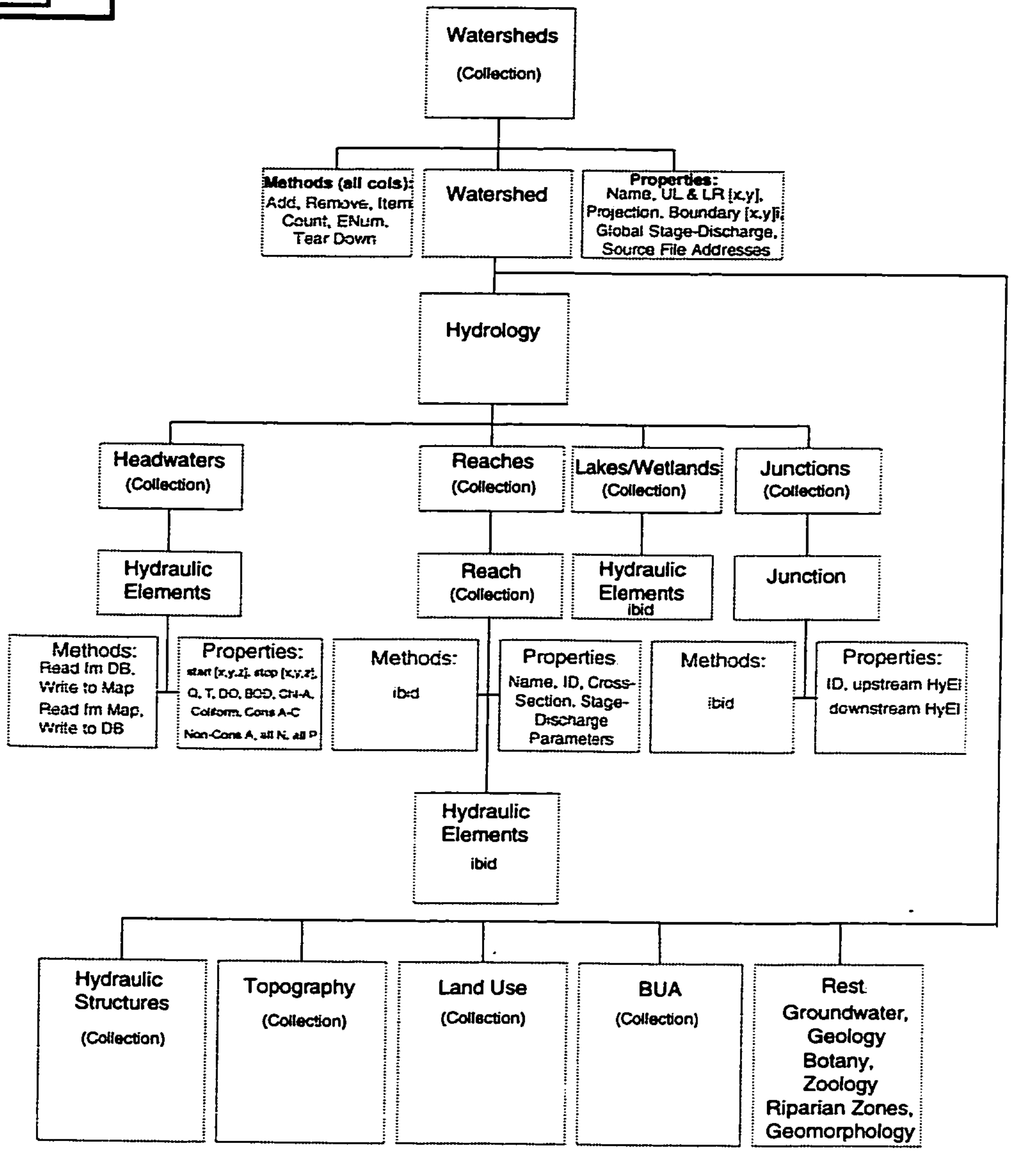


Figure 5-6. 1 of 4 WMDSS Watershed Object Model - Hydrology

WMDSS(EO)

WMDSS Object Model: Land Use, Built Up Areas and Hydraulic Structures

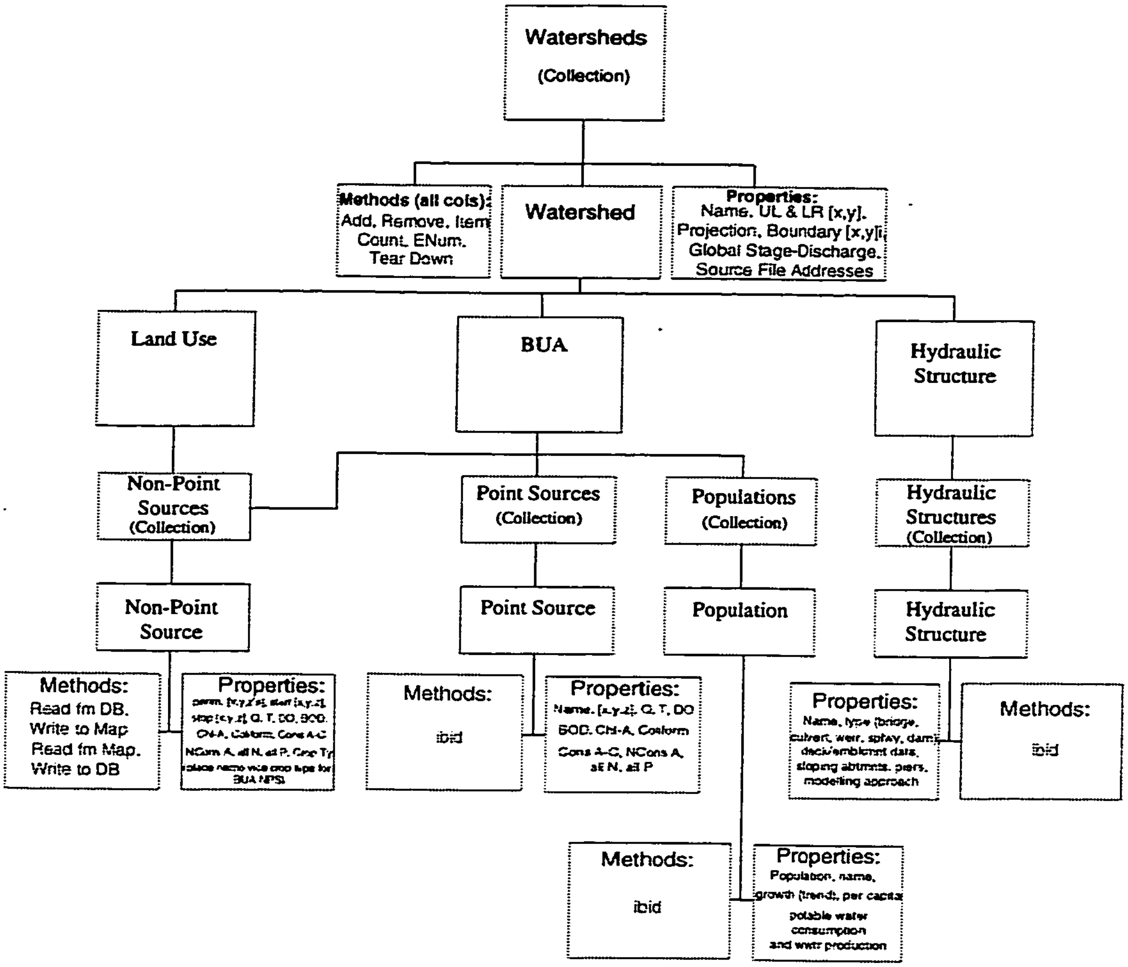


Figure 5-7. 2 of 4 WMDSS Watershed Object Model – Land Use, Built Up Areas, Hydraulic Structures

WMDSS(EO)

WMDSS Object Model: Topography, Groundwater and Geology

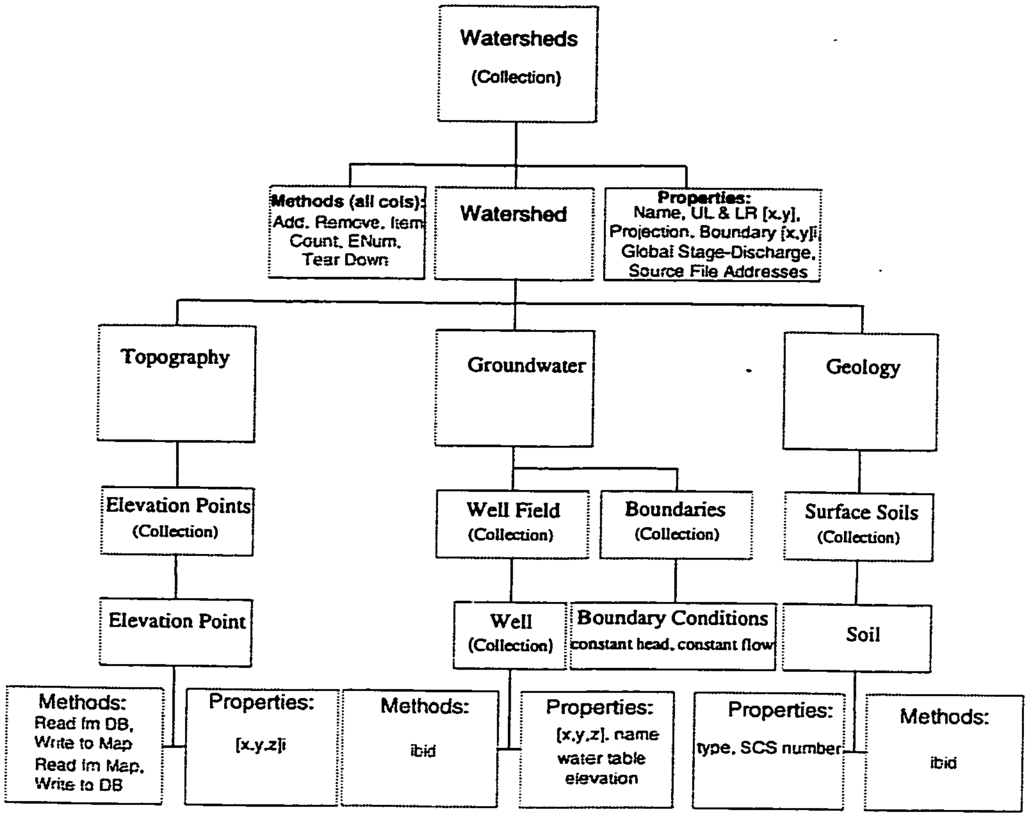


Figure 5-8. 3 of 4 WMDSS Watershed Object Model – Topography, Ground Water, Geology

WMDSS(EO)

WMDSS Object Model: Botany, Zoology, Riparian Zones, Geomorphology

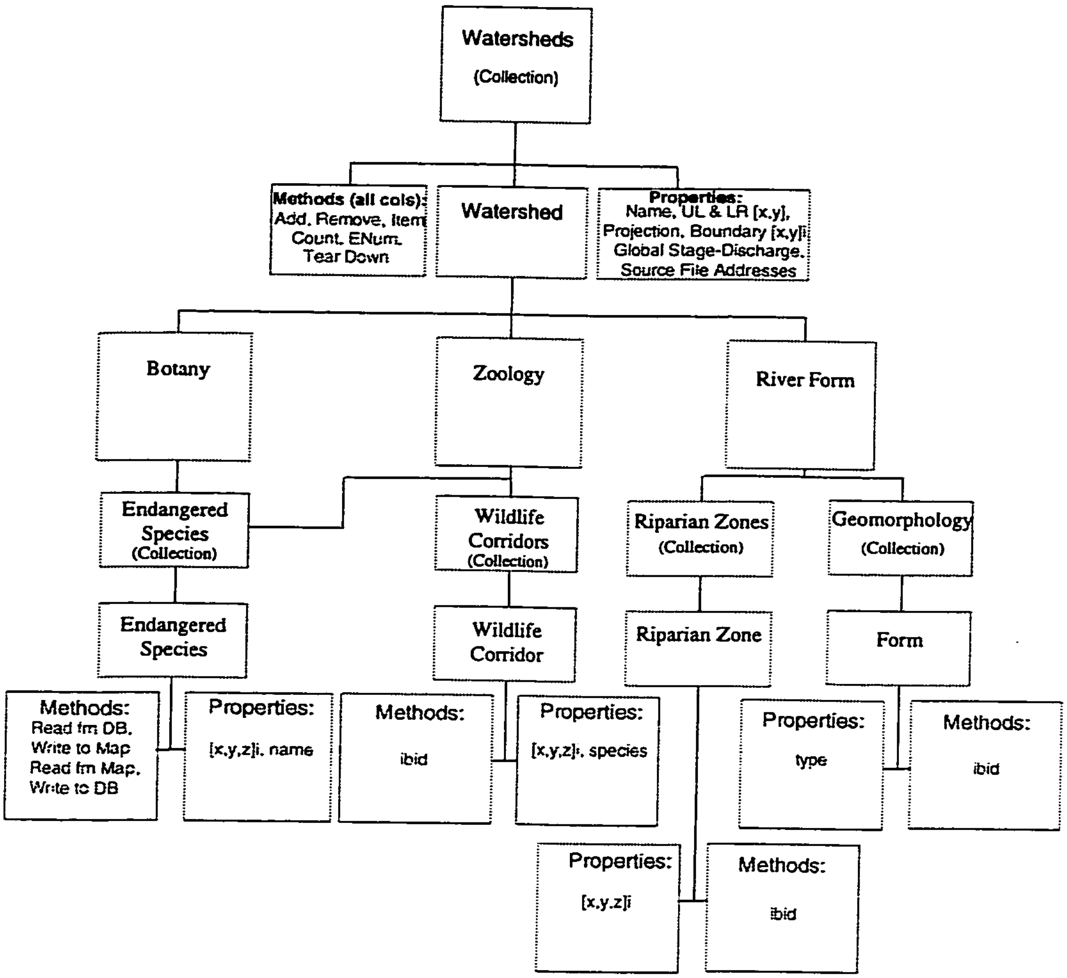


Figure 5-9. 4 of 4 WMDSS Watershed Object Model – Riparian Zones, Geomorphology, Zoology, Botany

Chapter 6. Program Design (Object-Oriented Design)

Having built the physical object model for the watershed elements that will underlay the application, the last task to complete prior to program validation is to design the actual application. The Alpha proof of concept application used for the validation has been 'frozen' and archived. The source code (approximately 20,000 lines) of VB5 program files will remain with the Department of Civil Engineering under the stewardship of Dr. R.L. Droste. Noting that the program code does not constitute part of this thesis (rather, the output of the Alpha product does), this section describes the program forms, modules and classes.

6.1. Program Components

In building the structure of the program, the sub-systems from Figure 3-5 are used. Descriptions of the program components follow:

1. DBMS. Components are:

   (a) Straight database interface (frmDocument) that provides a window to each industry standard database table (Access format) and to the text metafile for each watershed. The tables with their fields are as follows [brackets denote concentrations]:

      i. Settings – Fields are Upper Left X, Upper Left Y, Lower Right X, Lower Right Y, Projection (describes coordinate system used, eg. decimal lat/long), Stage-Discharge Parameters (flow and depth coefficients, Manning's number and dispersion coefficient) for all Headwaters, Perimeter XYs (break of land defining watershed), Surface Water Monitoring Filename, Ground Water Monitoring Filename, and Climatology Filename,

      ii. Hydraulic Elements – Fields are ID, Start X Y Z, End X Y Z, Flow, Temperature, [DO], [BOD], [Coliform], [Chlolophyll-A], [Organic N], [NH3], [NO2], [NO3], [Organic P], [Dissolved P], Conservative Substance A, [Conservative Substance A], Conservative Substance B, [Conservative Substance B], Conservative Substance C, [Conservative Substance C], Non-Conservative Substance A, [Non-Conservative Substance A], Reach ID, Reach Element ID, Headwater ID, Lake/Wetland ID, and Junction ID,

iii. Headwaters – Fields are Headwater ID, and Hydraulic Element ID,

iv. Reaches – Fields are Reach ID, Hydraulic Element ID, Name, Cross-Section XZs, and Stage-Discharge Parameters (flow and depth coefficients, Manning's number and dispersion coefficient),

v. Lakes/Wetlands – Fields are Lake/Wetland ID, Hydraulic Element ID, and Perimeter XYs,

vi. Reach Elements – Not used in current version,

vii. Junctions – Fields are Junction ID, Upstream Hydraulic Element ID, and Downstream Hydraulic Element ID,

viii. Hydraulic Structures – Not used in current version,

ix. Topography – Fields are Elevation ID, and X Y Zs,

x. Land Use – Fields are ID, Start X Y Z, End X Y Z, Flow, Temperature, [DO], [BOD], [Coliform], [Chlolophyll-A], [Organic N], [NH3], [NO2], [NO3], [Organic P], [Dissolved P], Conservative Substance A, [Conservative Substance A], Conservative Substance B, [Conservative Substance B], Conservative Substance C, [Conservative Substance C], Non-Conservative Substance A, [Non-Conservative Substance A], Perimeter XYs, Crop Type, Tillage, and Age,

xi. Built Up Areas – Fields are ID, Hydraulic Element ID, X Y Z, Name, Flow, Temperature, [DO], [BOD], [Coliform], [Chlolophyll-A], [Organic N], [NH3], [NO2], [NO3], [Organic P], [Dissolved P], Conservative Substance A, [Conservative Substance A], Conservative Substance B, [Conservative

Substance B], Conservative Substance C, [Conservative Substance C], [Non-Conservative Substance A], and Non-Conservative Substance A,

xii. Ground water – Not used in current version,

xiii. Geology – Not used in current version,

xiv. Botany – Not used in current version,

xv. Zoology – Not used in current version,

xvi. Riparian Zones – Not used in current version,

xvii. Geomorphology – Not used in current version;

(b) Graphical database interface (frmMapView) that provides a graphical view/build capability and populates watershed objects designed as per the OM specification;

(c) Module for the creation of a database file on commencement of creating a new watershed file (module Cr_Db); and

(d) Module for reading from and writing to the database file on commencement of or termination of a graphical view/build session (module RWOM).

2. <u>KBMS</u>. Components are:

(a) Integrated browser window (frmBrowser) that provides access to hyperlink document format references; and

(b) Management help files.

3. <u>MBMS</u>. Components are:

(a) QUAL2E interface (frmQual2E) that provides input screens similar to the QUAL2E windows version input screens allowing the user to select the watershed hydrologic components to be run through a water quality simulation;

(b) QUAL2E located in its own directory where the frmQUAL2E sends the generated input file after running the interface; and

(c) All modelling tools to subsequently be coupled will need a similar interface form (HEC-RAS, MODFLOW, HEC-HMS) or linked .dll files (Time Series Analysis, Ecological Index).

4. GUI. Components are:

(a) Main form of multiple document interface (MDI) that in addition to holding all other forms (excluding the About and Splash screens) has the file menus and toolbars for both file and model management (frmMain); and

(b) General module for program start up (module General) and user defined type initialisation.

5. Object Model. Classes are:

(a) Hydraulic Elements, including:

i. Reach Elements,

ii. Headwaters, and

iii. Lakes/Wetlands;

(b) Point Sources;

(c) Non-point Sources;

(d) Elevations; and

(e) Watersheds.

6. Report Generator. This will contain report generation forms (frmReport), likely based on integrated Excel components. Both in house data and output data from coupled models must be handled.

Each of the components is further described in detail in the following sections.

6.2. *Simple Database Interface*

This form (frmDocument) offers access to the database tables, for viewing and entry additions/editing. The data controls on each screen use commands from the Data Manipulation Language for access to data. The form also has a text window for viewing the metadata file (with extension .wmd) for the watershed, which holds information on the author of the watershed file, its creation date, and a running record of actions taken within the software.

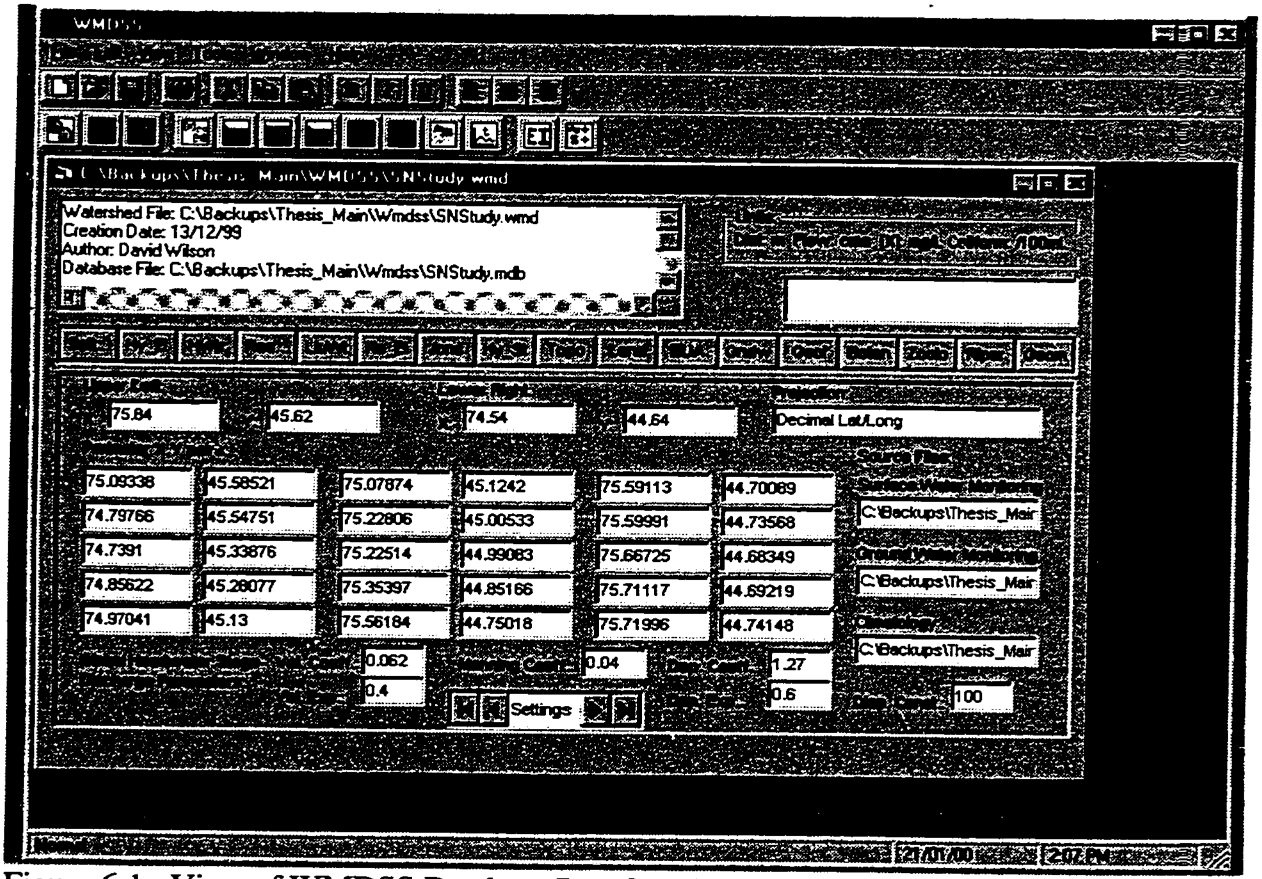


Figure 6-1. View of WMDSS Database Interface Screen

6.3. *Graphical View/Build Feature*

This form (frmMapView) is the heart of the WMDSS, offering a graphical user interface to both view and build watershed features. When loaded, this form calls the read/write module (see Section 6.5) to first populate the object model from the database, and then to render the object model on screen by layer as requested. Additional functions within the form provide calculation of scale, and rescale the watershed view when the user requires it. The scale is determined through the user supplying information on the type of projection used – scales with minimal longitudinal distortion such as Universal Transverse Mercator are therefore preferred. Other scales such as decimal latitude/longitude will induce X coordinate errors. Buttons along the top of the form select the desired layer to view, while buttons along the side initiate object creation for the various watershed elements. Movement of the mouse within the map window gives a display of the coordinate system coordinates at the bottom of the form. This screen is in essence a GIS-like interface to a watershed. At the end of a session with this form, newly created watershed objects are committed to the database through the same read/write module.

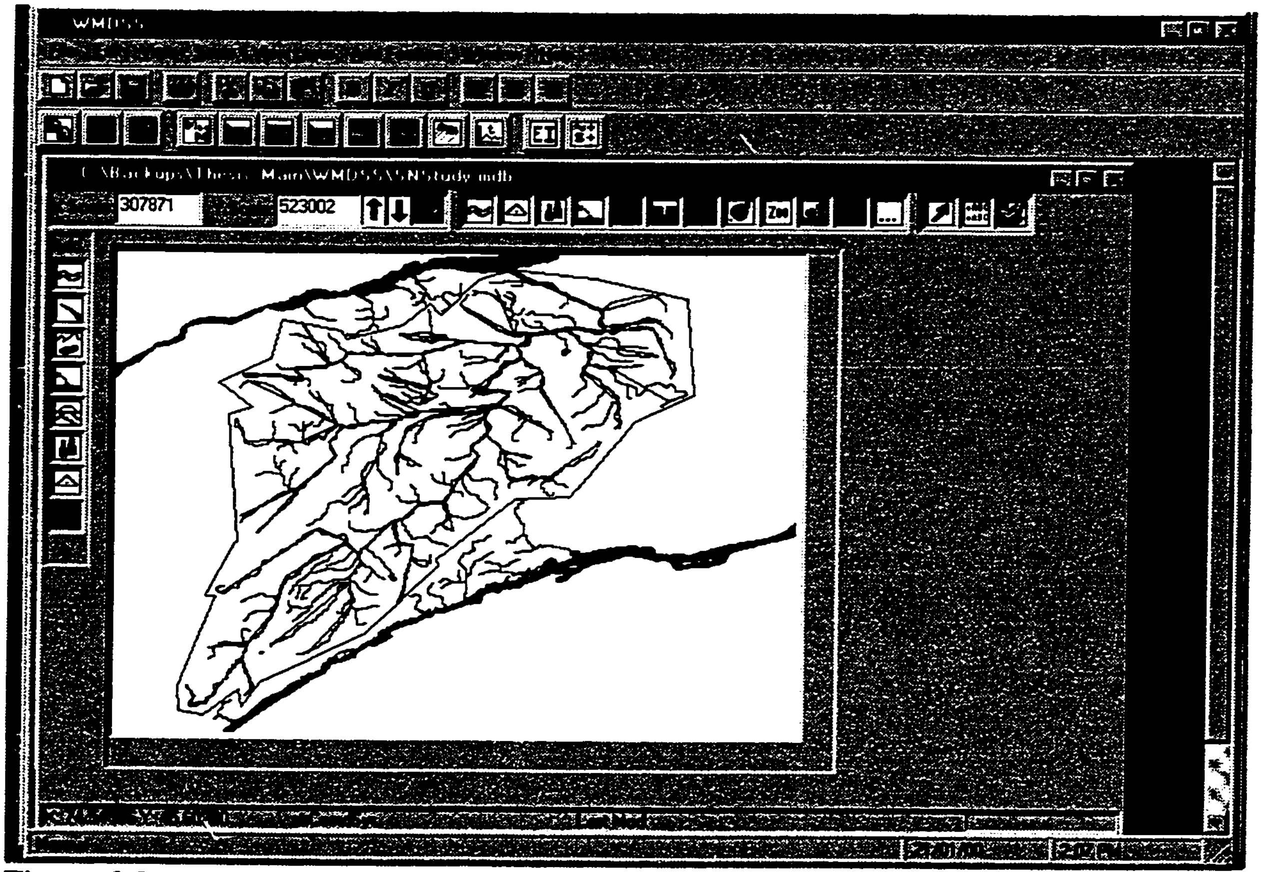


Figure 6-2. View of WMDSS Graphical View/Build Screen

6.4. *Watershed Database Creation*

On creation of a new watershed file, module Cr_Db creates a new watershed database file in Microsoft Access format using Database Design Language commands. The database is constructed as a replica of the OM template. This approach does generate inefficiencies in the database through replication of data elements (e.g., each entry in the hydraulic elements table has x, y and z values which are duplicated in the elevations table). However, it is felt that preservation of the object template is preferable to elimination of the duplication (through use of relational database features). Subsequent revision to the software may modify this approach once operating information has been gathered.

6.5. *Watershed Object Model Population*

During a graphical view/build session, reading from and writing to the database is enacted using module RWOM (for Read and Write to and from the Object Model). This module is called at the start or end of a session with frmMapView. Once frmMapView is loaded and the current database is mapped into object model variables, subsequent creation of watershed objects are initiated from within frmMapView based on user selection of the build tools along the left hand side. In order to give users the flexibility to add to an existing dataset anywhere within it, it is necessary to reset the applicable indexation values of all other elements affected by the creation of the new element. The indexation code written to enable this resides in the definition of the hydraulic element collection class module add function, as follows:

```
Public Function Add(ByVal ULocX As Single, ByVal ULocY As _
   Single, ByVal ULocZ As Single, ByVal LLocX As Single, _
   ByVal LLocY As Single, ByVal LLocZ As Single, ByVal _
   Flow As Double, ByVal Temp As Double, ByVal DOX As _
   Double, ByVal BOD As Double, ByVal ChlA As Double, _
   ByVal ConsA As String, ByVal ConcA As Double, ByVal _
   ConsB As String, ByVal ConcB As Double, ByVal ConsC _
   As String, ByVal ConcC As Double, ByVal NConsA As _
   String, ByVal NConcA As Double, ByVal Coli As Double, _
   ByVal OrgN As Double, ByVal NH3 As Double, ByVal NO2 _
   As Double, ByVal NO3 As Double, ByVal OrgP As Double, _
```

```
ByVal DisP As Double, ByVal HyElType As HyElType, ByVal _
JcnID As Integer, Optional ByVal TypeID As Integer, _
Optional ByVal ReID As Integer, Optional ByVal NewRe _
As Boolean) As HyEl
'create a new object
Static intHyElNum As Integer
Static intHwtrNum As Integer
Static intHwtrMax As Integer
Static intReElNum As Integer
Static intJcnNum As Integer
Static intReNum As Integer
Static intReMax As Integer
Static intLWNum As Integer
Static intLWMax As Integer
Dim intRank As Integer
Dim i As Integer
Static sngZs() As Single
Static sngReReEls() As Single
Static strLaReID As String

'set the properties passed into the method
ReDim Preserve sngReReEls(1, intHyElNum + 1)
If Not IsMissing(TypeID) And TypeID > 0 Then 'read db situation
  Select Case HyElType
    Case hetHwtr
      intHwtrNum = TypeID
      If TypeID > intHwtrMax Then
        intHwtrMax = TypeID
      End If
      hyelNew.TypeID = "Hwtr" & Format$(TypeID, "000")
    Case hetReEl
      intReElNum = TypeID
      If ReID > intReMax Then
        intReMax = ReID
      End If
      intReNum = ReID
      hyelNew.TypeID = "ReEl" & Format$(TypeID, "000")
      hyelNew.ReID = "Re" & Format$(ReID, "000")
```

```
            strLaReID = "Re" & Format$(intReNum, "000")
          Case hetLW
            intLWNum = TypeID
            If TypeID > intLWMax Then
              intLWMax = TypeID
            End If
            hyelNew.TypeID = "LW" & Format$(TypeID, "000")
          Case Else
            Err.Raise Number:=vbObjectError + 32113, _
              Description:="Invalid HyEl Type"
        End Select
        ReDim Preserve sngZs(intHyElNum + 1)
        sngZs(intHyElNum) = ULocZ
        intJcnNum = JcnID
      Else 'i.e., typeID missing therefore "add new" situation
        Select Case HyElType 'and new reach, not adding to old
          Case hetHwtr
            intHwtrNum = intHwtrMax + 1
            intHwtrMax = intHwtrNum
            hyelNew.TypeID = "Hwtr" & Format$(intHwtrNum, "000")
          Case hetReEl
            If NewRe = True Then
              intReNum = intReMax + 1
              intReMax = intReNum
              intReElNum = 0
            ElseIf ReID > 0 Then
              For i = 1 To intHyElNum + 1
                If sngReReEls(0, i) = ReID Then intReElNum = sngReReEls(1, i)
              Next i
              intReNum = ReID
            End If
            intReElNum = intReElNum + 1
            hyelNew.TypeID = "ReEl" & Format$(intReElNum, "000")
            hyelNew.ReID = "Re" & Format$(intReNum, "000")
            strLaReID = "Re" & Format$(intReNum, "000")
          Case hetLW
            intLWNum = intLWMax + 1
            intLWMax = intLWNum
```

```
            hyelNew.TypeID = "LW" & Format$(intLWNum, "000")
          Case Else
            Err.Raise Number:=vbObjectError + 32113, _
              Description:="Invalid HyEl Type"
        End Select
        intRank = 0
        ReDim Preserve sngZs(intHyElNum + 1)
        Do While ULocZ < sngZs(intRank)
          intRank = intRank + 1
        Loop
        If JcnID = 1 Then 'either join to existing or make new
          intJcnNum = intJcnNum + 1
          JcnID = intJcnNum
        ElseIf JcnID = 0 Then
          JcnID = 0
        End If
      End If
      sngReReEls(0, intHyElNum + 1) = intReNum
      sngReReEls(1, intHyElNum + 1) = intReElNum
      With hyelNew
        intHyElNum = intHyElNum + 1
        .ID = "HyEl" & Format$(intHyElNum, "000")
        .ULocX = ULocX
        .ULocY = ULocY
        .ULocZ = ULocZ
        .LLocX = LLocX
        .LLocY = LLocY
        .LLocZ = LLocZ
        .Flow = Flow
        .Temp = Temp
        .DOX = DOX
        .BOD = BOD
        .ChlA = ChlA
        .ConsA = ConsA
        .ConcA = ConcA
        .ConsB = ConsB
        .ConcB = ConcB
        .ConsC = ConsC
```

```
        .ConcC = ConcC
        .NConsA = NConsA
        .NConcA = NConcA
        .Coli = Coli
        .OrgN = OrgN
        .NH3 = NH3
        .NO2 = NO2
        .NO3 = NO3
        .OrgP = OrgP
        .DisP = DisP
        .JcnID = JcnID
        .HyElType = HyElType
        'send ID info to MapView
        Call frmMV.LastHyEl(.ID, .TypeID, .JcnID, strLaReID)
        If intRank > 0 Then
          mcolHyEls.Add Item:=hyelNew, Key:=.ID, after:=intRank
        Else
          mcolHyEls.Add Item:=hyelNew, Key:=.ID
        End If
    End With

    'return the object created
    Set Add = hyelNew
    Set hyelNew = Nothing

End Function
```

The TypeID variable is used to indicate whether the new hydraulic element is to be a reach element, headwater or lake/wetland. Additionally, the absence of the TypeID indicates that the element is new to the database (i.e. not having been created during the running of the RWOM module at form load), and so requires assessment as to where it belongs.

6.6. *Reference/Expert Knowledge*

The Knowledge Base requirement is met through use of an integrated browser, frmBrowser, that can be used to access pertinent reference information available in hypertext markup language document format.

6.7. *Water Quality Modelling*

The interface to the coupled water quality model QUAL2E is handled with frmQUAL2E, which provides replication of the windows version of QUAL2E input screens and subsequent translation of the WMDSS OM to the QUAL2E OM. In order to accomplish this translation, two approaches could have been taken. Firstly, one could map WMDSS reaches directly to QUAL2E reaches, averaging the variable length WMDSS hydraulic elements into QUAL2E hydraulic elements of uniform length; secondly, one could map WMDSS hydraulic elements to QUAL2E reaches. Due to the restrictions on number of elements QUAL2E can handle, the second approach is untenable. The form greatly simplifies the input of reach data over the QUAL2E version by using the physical information of the hydraulic elements available to WMDSS. Once the user selects the elements for which a simulation is desired, the form calculates reach lengths and accesses the pertinent flow, temperature and constituent concentration information. This step is the key to the interface operation, and is replicated below:

```
Private Sub CalcEle()

    Dim strQuery As String
    Dim strStrOne As String
    Dim strStrTwo As String
    Dim strStrThree As String
    Dim i As Integer
    Dim rcdCount As Integer
    Dim intInt As Integer
    Dim sngX As Single
    Dim sngY As Single
    Dim sngREl() As Single
    Dim intReID() As Integer
    Dim intJcnID As Integer
```

```
Dim sngLen As Single
Dim blnBln As Boolean
Dim MyCheck
Dim MyCheck2
Dim MyCheck3

' On Error GoTo Err_Hand
'collect db info
Set wspCurrent = DBEngine.Workspaces(0)
Set dbDb = OpenDatabase(mstrDbTit, , True)
wspCurrent.BeginTrans
intInt = lstQ2E(3).ListCount
strStrOne = "": strStrTwo = ""
strStrThree = "": mstrStrThree = ""
For i = 0 To intInt - 1 'lw first
   strStrOne = strStrOne & Mid(lstQ2E(3).List(i), _
   Len(lstQ2E(3).List(i)) - 1, 2) ' only reads 1-or2-digit HyEls!
   If i < intInt - 1 Then strStrOne = strStrOne & " OR [HyElID] = "
Next i
intInt = lstQ2E(5).ListCount
For i = 0 To intInt - 1 'hw now
   strStrOne = strStrOne & Mid(lstQ2E(5).List(i), _
   Len(lstQ2E(5).List(i)) - 1, 2) ' only reads 1-or2-digit HyEls!
   If i < intInt - 1 Then strStrOne = strStrOne & " OR [HyElID] = "
Next i
intInt = lstQ2E(7).ListCount
For i = 0 To intInt - 1 'pt srce now
   strStrTwo = strStrTwo & """" & lstQ2E(7).List(i) _
     & """" 'reads Name
   If i < intInt - 1 Then strStrTwo = strStrTwo & " OR Name = "
Next i
intInt = lstQ2E(1).ListCount
For i = 0 To intInt - 1 're last
   strStrThree = strStrThree & Mid(lstQ2E(1).List(i), _
   Len(lstQ2E(1).List(i)) - 1, 2) ' only reads 1-or2-digit HyEls!
   mstrStrThree = mstrStrThree & Mid(lstQ2E(1).List(i), _
   Len(lstQ2E(1).List(i)) - 1, 2)
   If i < intInt - 1 Then
```

```
            strStrThree = strStrThree & " OR [ReID] = "
            mstrStrThree = mstrStrThree & " OR Reaches.ReID = "
          End If
        Next i
        strQuery = "SELECT * FROM [Hydraulic Elements] WHERE " _
          & "[HyElID] = " & strStrOne & " OR [ReID] = " _
          & strStrThree & " ORDER BY [HyElID]"
        Set rcdSet = dbDb.OpenRecordset(strQuery, _
          dbOpenDynaset, dbReadOnly, dbReadOnly)
        strQuery = "SELECT * FROM [Point Sources] WHERE " _
          & "[Name] = " & strStrTwo & " ORDER BY [HyElID]"
        Set rcdSetTwo = dbDb.OpenRecordset(strQuery, _
          dbOpenDynaset, dbReadOnly, dbReadOnly)
        mintQ2ERe = lstQ2E(3).ListCount + lstQ2E(5).ListCount + _
          lstQ2E(1).ListCount
        ReDim msngRLen(mintQ2ERe): ReDim msngSt(mintQ2ERe)
        ReDim msngEn(mintQ2ERe): ReDim mstrRNm(mintQ2ERe)
        ReDim sngREl(150): ReDim intReID(150)
        ReDim mintRank(mintQ2ERe): ReDim mstrREls(15, mintQ2ERe)
        ReDim mstrDelX(mintQ2ERe): ReDim mstrNumEls(mintQ2ERe)
        ReDim mstrRQualPs(16, mintQ2ERe)
        With rcdSet
          .MoveFirst
          i = 0 '1st hyel is hw
          Do Until .EOF
            MyCheck = IsNumeric(![HwID]): MyCheck2 = IsNumeric(![LWID])
            MyCheck3 = IsNumeric(![ReID])
            If MyCheck = True Or MyCheck2 = True Then
              msngRLen(i) = Sqr((mXFac * (![End Loc X] - ![Start Loc X])) ^ 2 _
                + (mYFac * (![End Loc Y] - ![Start Loc Y])) ^ 2)
              If !HwID > 0 Then
                mstrRNm(i) = "Hw" & !HwID & " HyElID  " & !HyElID
              Else
                mstrRNm(i) = "LW" & !LWID & " HyElID  " & !HyElID
              End If
              If i < 10 Then
                txtQ2E(i + 65).Text = mstrRNm(i)
                txtQ2E(i + 75).Text = msngRLen(i)
```

```
Else
   txtQ2E(i + 266).Text = mstrRNm(i)
   txtQ2E(i + 268).Text = msngRLen(i)
End If
mstrRQualPs(0, i) = !Temp
mstrRQualPs(1, i) = !Conc_DO
mstrRQualPs(2, i) = !Conc_BOD
mstrRQualPs(3, i) = !Conc_A
mstrRQualPs(4, i) = !Conc_B
mstrRQualPs(5, i) = !Conc_C
mstrRQualPs(6, i) = !Conc_N_A
mstrRQualPs(7, i) = !Coliform
mstrRQualPs(8, i) = !Chl_A
mstrRQualPs(9, i) = ![Org N]
mstrRQualPs(10, i) = !NH3
mstrRQualPs(11, i) = !NO2
mstrRQualPs(12, i) = !NO3
mstrRQualPs(13, i) = ![Org P]
mstrRQualPs(14, i) = !Diss_P
mstrRQualPs(15, i) = !Vol_Flow
i = i + 1
.MoveNext 'check 2nd hyel for hw or re
ElseIf MyCheck3 = True Then
   If .EOF = False Then
      sngREl(!ReID) = sngREl(!ReID) + Sqr((mXFac * (![End Loc X] -
![Start Loc X])) ^ 2 _
         + (mYFac * (![End Loc Y] - ![Start Loc Y])) ^ 2)
      .MoveNext
   End If
   If .EOF = True Then
      .MoveFirst
      Do While .EOF = False
         MyCheck3 = IsNumeric(![ReID])
         If MyCheck3 = True Then
            If !ReID = intReID(!ReID) Then
               blnBln = True
            Else
               blnBln = False
```

```
            End If
          End If
          If MyCheck3 = True And blnBln = False Then
            intReID(!ReID) = !ReID
            msngRLen(i) = sngREl(!ReID)
            mstrRNm(i) = "Re" & !ReID & " HyElID  " & !HyElID
            If i < 10 Then
              txtQ2E(i + 65).Text = mstrRNm(i)
              txtQ2E(i + 75).Text = msngRLen(i)
            Else
              txtQ2E(i + 266).Text = mstrRNm(i)
              txtQ2E(i + 268).Text = msngRLen(i)
            End If
            mstrRQualPs(0, i) = !Temp
            mstrRQualPs(1, i) = !Conc_DO
            mstrRQualPs(2, i) = !Conc_BOD
            mstrRQualPs(3, i) = !Conc_A
            mstrRQualPs(4, i) = !Conc_B
            mstrRQualPs(5, i) = !Conc_C
            mstrRQualPs(6, i) = !Conc_N_A
            mstrRQualPs(7, i) = !Coliform
            mstrRQualPs(8, i) = !Chl_A
            mstrRQualPs(9, i) = ![Org N]
            mstrRQualPs(10, i) = !NH3
            mstrRQualPs(11, i) = !NO2
            mstrRQualPs(12, i) = !NO3
            mstrRQualPs(13, i) = ![Org P]
            mstrRQualPs(14, i) = !Diss_P
            mstrRQualPs(15, i) = !Vol_Flow
            i = i + 1
            blnBln = True
          End If
          .MoveNext
        Loop
      End If
    End If
  Loop
End With
```

```
        wspCurrent.Rollback
        rcdSet.Close
        rcdSetTwo.Close
        dbDb.Close
        Set wspCurrent = Nothing
    '   Exit Sub

    'Err_Hand:
    '   If Err = 3075 Then
    '       MsgBox "Need to be able to select 0 ps"
    '       Resume Next
    '   Else
    '       MsgBox "Err #" & Err
    '       Resume Next
    '   End If

    End Sub
```

6.8. Remainder of Physical Models

Each of the remaining physical models will require a similar interface. Having already taken into account the data requirements of the other models in creation of the WMDSS data and object models simplifies this process significantly, however.

6.9. Multiple Document Interface

WMDSS uses a multiple document interface format, such that all forms stay within the main form (frmMain) during operation. FrmMain also holds the menu bar and the file and tool toolbars.

6.10. Start Module

Control of program start up is handled in the start module General, which brings up the splash screen followed by the main form.

6.11. *Object Model*

The WMDSS object model finds realisation in the collections and classes modules that are templates for the objects. Strict type control is enabled through the definitions of the classes, such that users must provide data of the required types to initiate object instantiation. Collection classes are used to hold and control object creation.

6.12. *Data Display*

Currently data display is only available within frmMapView. Extensions to the Alpha product call for a suite of data visualisation tools, likely to be imported Excel graphing objects.

6.13. *Extension to Beta Product*

The work necessary to take the Alpha proof of concept to a Beta level is as follows:

1. Completion of WMDSS functionality up to beta status, as follows:

   (a) complete all error checking/trapping routines;

   (b) build report generation/data display capabilities using Excel components for the most part;

   (c) build an ActiveX main page for the browser that provides active links to in house references;

   (d) build an ArcView/ArcInfo GIS import/export interface using the ASCII raster format;

   (e) HEC-RAS interface (including the sedimentation module once available);

   (f) MODFLOW/MFI interface;

   (g) HEC-HMS interface;

   (h) link in house functions as .dll files for time series analysis;

(i) select an Ecological Index and implement; and

(j) implement integration features.

2. Establish a joint centre of excellence with industrial and public partner(s) (if any) to foster commercial and public use of the WMDSS while making it available for research at the University of Ottawa.

Chapter 7. Validation with Real World Problem

The final phase of the project involves validating the software tool by performing an analysis of a real world problem. Validation seeks to assess whether or not the system meets stated requirements. This section also provides verification of the program code, i.e., has the program been coded correctly.

The real world problem examined at is the surface water quality of the South Nation Basin in Eastern Ontario. This watershed has seen significant study over the years, including the *South Nation River Basin Water Management Study* (SNRCA, 1983), the *Wastewater Assimilation Study of the South Nation River Watershed* (Gore and Storrie, 1993), and the report on *Groundwater Issues in the South Nation River Region* (SNRCA, 1997). It is currently a significant part of the broad initiative Eastern Ontario Water Resources Management Study. As an agricultural watershed, it suffers from large nutrient inflows – coupled with the anthropogenic point source discharges, much of its assimilative capacity is used, indeed, overused at times. Following up on a body of research commencing with the Wastewater Allocation Study of the South Nation River (Gore and Storrie, 1992), the validation phase will analyse the basin to determine the relative importance of point and non-point sources to the river's water quality. The 1992 study concluded that on an annual basis the major sources of ammonia and phosphorus were non-point sources, to the extent that nitrogen and phosphorus loads contributed by these non-point sources constituted greater than 98 and 93% respectively of the total load. Growth figures produced at the time forecast a doubling of the watershed population by 2001, generating grave concerns that the assimilative capacity of the river would be greatly exceeded. Examination of dissolved oxygen (DO) was restricted to known point sources, and to a theoretical treatment of the subject. Validation and expansion of this early analysis will give clear emphasis on the necessity of addressing water quality in the basin through non-point source abatement measures, the success of which are central to removing wastewater assimilative capacity as a growth limiting factor for the region.

This validation is specifically aimed at replicating the DO analysis. Influences on modelled DO take into account biochemical oxygen demand (BOD) exertion, nitrification of ammonia, and reaeration (of flow, not as a result of passage over a hydraulic structure). The influences of sediment oxygen demand (SOD) were included as well. This led to use of a modified Streeter–Phelps equation as described in Equation 5.

It should be noted that QUAL2E includes provision for incremental inflows along river reaches, which with quality characterisation can provide an inroad into non-point source modelling. Also of note is the fact that flows in QUAL2E are calculated using either stage-discharge relationships or through use of trapezoidal channels of a given slope. As this analysis will show, obtaining meaningful stage-discharge coefficients throughout the basin is problematic – this leaves the simulation subject to the inaccuracies resultant from estimated time of travel and reach width values. The stage-discharge relationships used in QUAL2E take the form of the following expressions:

$d = bQ^{x2}$ (6) $v = aQ^{x1}$ (7)

where

d = depth (m) v = velocity (m/s)

Q = flow (m^3/s) a,b,x_1,x_2 = constants

such that stream width w (m) and cross section A_x (m^2) are found as follows:

$A_x = w \times d = Qv$ (8) $w = Qv/d$ (9)

7.1. Specific Objectives

1. To validate WMDSS by running the Gore & Storrie Waste Water Allocation Study point source water quality analysis for DO [Gore and Storrie, 1992] in WMDSS.

2. To highlight the potential for integrated watershed management through use of the WMDSS approach by initiating definition if informational layers of the watershed in addition to those strictly necessary for point source water quality analysis.

3. To verify the coding of WMDSS.

7.2. *Methodology*

7.2.1. Methodology of the Previous Study

The previous study's objectives were to evaluate the impact of point source discharges on DO, NH_3-N, and sulfides in the surface waters under present and future conditions (Gore & Storrie, 1992). The future condition was the population figures projected by the communities in 20 years along with any changes in wastewater production by industries in the watershed. The impacts of the point source waste discharges were to be evaluated at 7Q20 and 30Q20 stream flow conditions.

An in-house frequency flow analysis program was used to fit flows to a Gumbel Type III frequency distribution and determine 7 and 30 day average flows to find the 7Q20 and 30Q20 flows in all reaches. Headwaters and other low flow reaches were not included.

Historical data for the communities and typical design data were used to determine the wastewater flow rates from communities under future conditions where changes in wastewater collection practice were anticipated. All municipal effluents were treated with stabilization pond systems. Discharges from the ponds are manually controlled and discharge occurred in the spring and fall only. Likewise effluent from industrial sources could be discharged continuously or stored and discharged during the spring and fall. Effluent quality from the ponds was specified along with effluent quality from other types of treatment (which could be considered) by the regulatory authority. Industrial discharge quantity and quality were based on recorded data and future projections.

The 7Q20 low flows were judged to be too conservative and 30Q20 flows were used for the major conclusions from the study. A dendritic diagram of the system was produced. Reaches were identified by confluences or point source additions. A spreadsheet was used to solve the modified Streeter-Phelps equation (5) on a reach-by-reach basis with the effluents from all point sources at the qualities specified discharged into the 30Q20 stream flows. The discharges were assumed to occur at a constant rate.

The discharge window (time over which the effluent reservoirs were emptied) resulting in the minimum deterioration in streams' qualities was determined.

7.2.2. Production of a WMDSS South Nation Database File

The first step to be carried out was to construct the WMDSS source file in the software tool. This can be done either from scratch within the tool or using picture templates from which to add features (templates from, for example, a GIS file). A true GIS import routine is forthcoming. The stream network template shown in Figure 7-1 is derived from a 1:50,000 shapefile (National Terrain Database) provided under license from Natural Resources Canada.

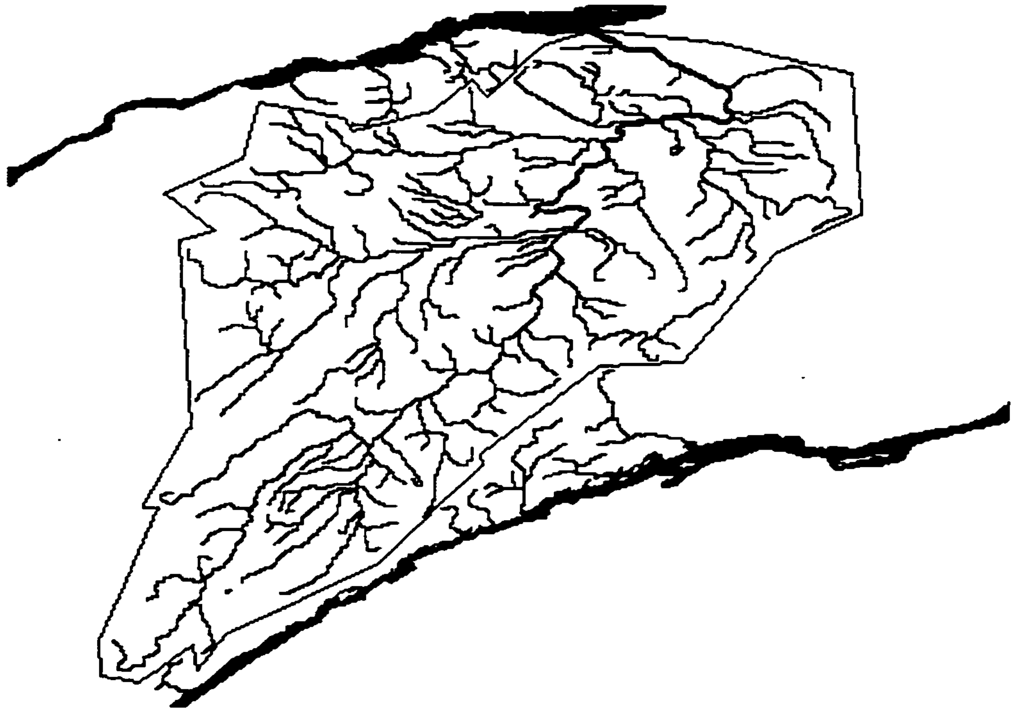


Figure 7-1. Stream Network (adapted from ArcView shapefile 1:50000 © Her Majesty the Queen in Right of Canada, Reproduced with Permission of Natural Resources Canada)

Taking the above stream network and producing the WMDSS hydraulic elements layer is then a straightforward process of copying the relevant stream courses and inputting the flow, elevation and constituent concentration data. The figure provided the template upon which the stream network was constructed in WMDSS using the graphical view/build screen, as depicted in Figure 7-2. On screen elements are rendered as objects according to the object model built in step 5 of the systems analysis process mentioned earlier. Objects are saved to a relational database once the graphical session is complete. A selection of hydraulic elements and point sources from the South Nation database are given in Table 7-1, while a map view of the complete WMDSS South Nation file can be seen along with the QUAL2E run groups in Figure 7-6. Characterisation of the complete stream network required construction of 118 hydraulic elements, 35 of them being headwater elements with the remainder being reaches composed of from one to four elements.

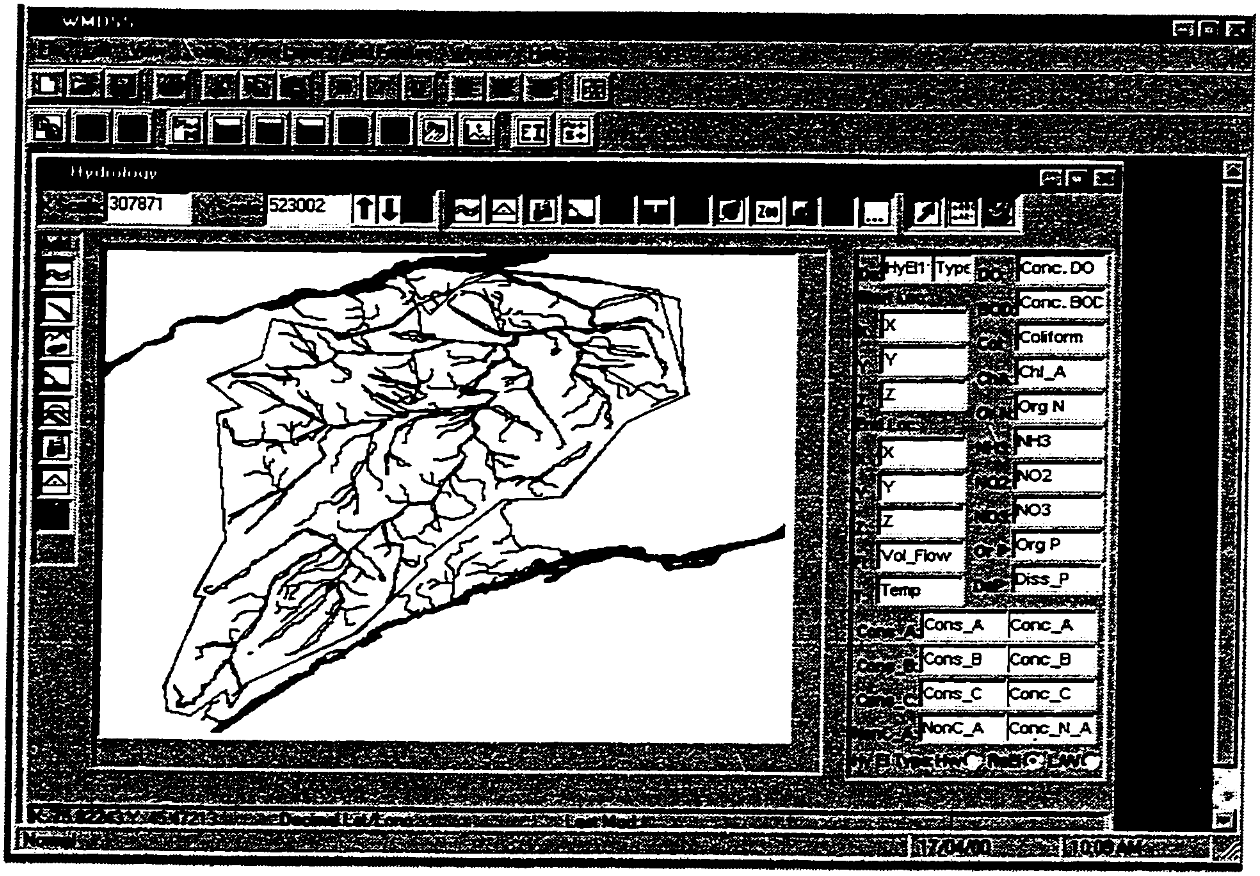


Figure 7-2. WMDSS Graphical View/Build Screen

In addition to start and end X,Y coordinate values, hydraulic elements also have start and end Z values (elevation), temperature, volumetric flow and constituent concentration values for DO, BOD, NH_3, NO_2, NO_3, organic N, organic P, dissolved P, three arbitrary conservative substances and one arbitrary non-conservative substances, in line with the data requirements of QUAL2E. Other data necessary for simulation include stage-discharge parameters (defined globally for all headwater elements and individually by reach) and the environmental and kinetic parameters influencing in stream chemical transformations.

The analysis was carried out by running a series of QUAL2E simulations with the rate constants and background constituent concentrations from the '92 report cited above, summarized in Table 7-2. Due to the element limitations of QUAL2E, multiple runs were necessary. Seven such runs were done, covering the areas outlined on the WMDSS watershed network figure (Figure 7-5). Final constituent concentrations and flows from an upstream run became the input values for the starting reach of the following run. Point source data were also as per the '92 report (Table 7-3), while the scenario followed was the spring 30Q20 average window present conditions analysis.

7.3. Results

7.3.1. Running the WMDSS QUAL2E Interface

The first step in using the WMDSS QUAL2E interface was to produce a test file of exact proportions to a section of the 1992 study to ensure matching results were obtained. This was done on a simplified version of run #1 where the SOD parameter was set to zero – the 1992 study excluded SOD from the spring analysis on the basis that scour was sufficient to eliminate the effect. Figures 7-3 and 7-4 show the construction of the QUAL2E input file from the study data and output from QUAL2E for the test run with data points from the 1992 study overlain. Good agreement is shown for flow, and DO and BOD match well (the QUAL2E run shows slightly lower BOD levels due to the exertion occuring in the minimum length headwater reach of the QUAL2E file). Once the interface was seen to be working correctly SOD was added at a level of 20% of the fall value for k_s (1 g/m^2/d) which was deemed more representative of actual conditions along the major water courses during spring conditions. Rationale for this step comes from observation of the major watercourses of the basin, many of which exhibit significant organic benthic layers year round. Choice of the value is borne out in the literature (Tetra Tech, 1978) where values for the areal rate of SOD range from 0.1 – 10.0 g/m^2/d.

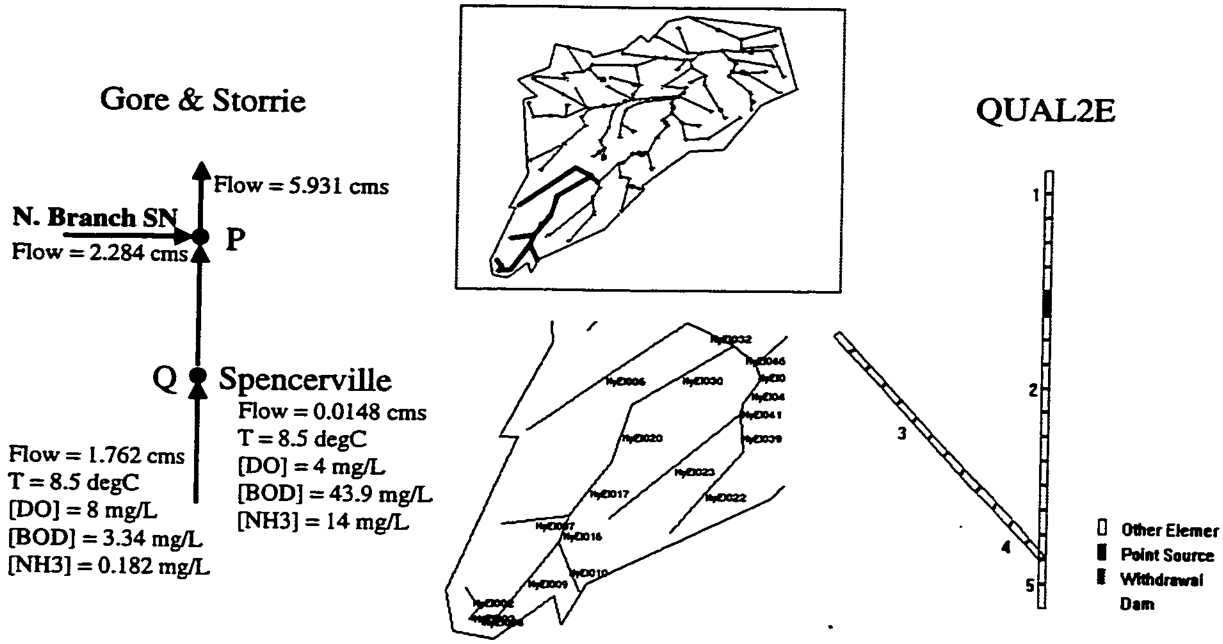


Figure 7-3. Construction of QUAL2E Test File using 1992 Study Data

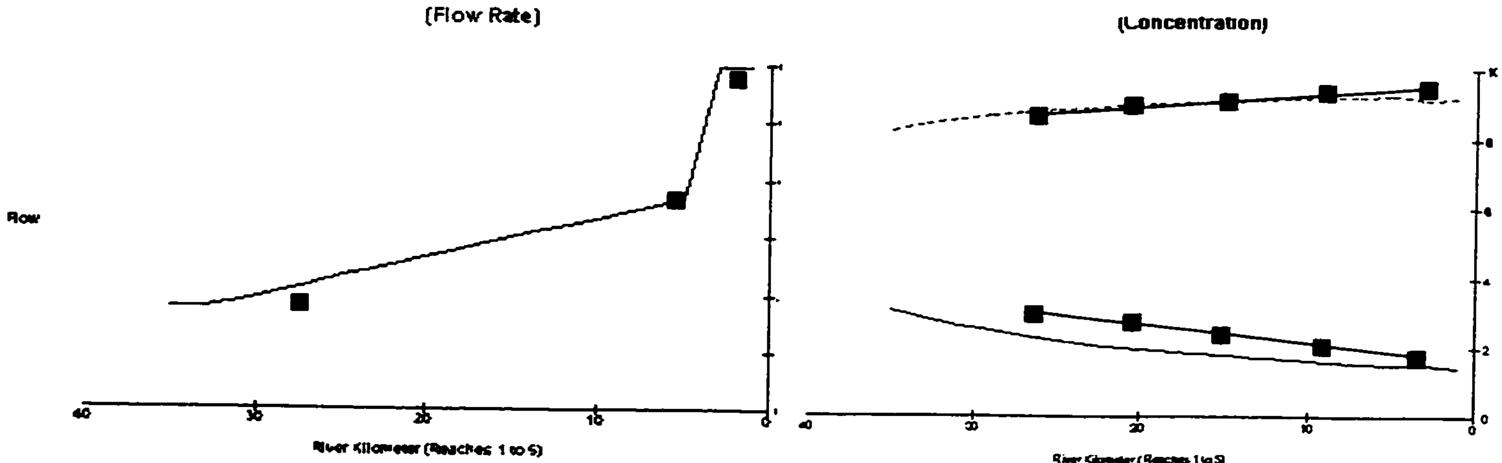


Figure 7-4. Output from QUAL2E Test Run with 1992 Study Data Overlain

Figure 7-5 is a view of the WMDSS stream network produced, with point sources represented as filled circles. Located around the image are the seven QUAL2E input files produced by running the WMDSS QUAL2E interface. The groups of dotted lines are replications of the sections of the basin grouped into each of the runs. The purpose of the interface is to automate the process of generating model input files such that it becomes unnecessary to have separate stream network representations in each of the tools coupled to the management system. Table 7-4 is an example of one of the input file summaries with the relevant stream parameters calculated.

Hy EIID	Start Loc X	Start Loc Y	Start Lc Z	End Loc X	End Loc Y	End Z	Flow	Temp	D O	BOD	Re ID	Hw ID	Jcn ID
1	74.79212	45.32455	111	74.90435	45.39085	56	0.3	8.5	8	3.37		35	33
2	75.69863	44.74375	108	75.68258	44.72071	103	0.3	8.5	8	3.37		1	1
3	75.68258	44.72071	103	75.69425	44.70629	100	0.5	8.5	8	3.37	1		1
4	74.78338	45.37931	101	74.82273	45.47299	61	0.2	8.5	8	3.37		39	36
5	74.92183	45.24097	100	75.02094	45.16891	80	0.3	8.5	8	3.37		10	10
6	75.63304	44.93255	100	75.45087	45.06370	80	0.5	8.5	8	3.37		4	3
7	75.65927	44.82014	100	75.58350	44.83023	91	0.5	8.5	8	3.37		3	2
8	75.69425	44.70629	100	75.66219	44.71062	98	0.6	8.5	8	3.37	1		1
9	75.66211	44.71062	98	75.59515	44.79853	92	0.8	8.5	8	3.37	1		1

PtSrceID	LocX	LocY	Loc Z	Name	Flow	Temp	DO	BOD	NH3	HyEl ID
1	75.55872345	44.86771011	90	Spencerville	0.015	8.5	4	43.9	14	17
2	75.35614014	45.10261917	71	Winchester	0.182	8.5	4	43.9	14	54
3	75.24099731	45.11846924	68.5	Chesterville	0.086	8.5	4	43.9	14	68
4	75.25995636	45.0017395	81	Williamsburg	0.019	8.5	4	43.9	14	27
5	75.23226166	45.11270905	68.5	Nestle	0.065	8.5	4	43.9	14	68
6	75.15794373	45.222229	58.4	Crysler	0	8.5	4	43.9	14	94
7	75.13316345	45.27122879	58	St.Albert	0	8.5	4	43.9	14	95
8	75.13316345	45.27843857	57.7	St.Albert Cheese	0	8.5	4	43.9	14	95

Table 7-1. A Selection of Hydraulic Elements and Point Sources in WMDSS South Nation Database (Initial Conditions)

Coefficient/Constituent	Range	Trial #1 Value	θ
BOD decay k_1 (d^{-1})	0.05-0.50	0.50	1.047
Reaeration k_2 (d^{-1})	0.8-4.0	0.8	1.024
Nitrification k_N (d^{-1})	0.1-1.0	1.0	1.083
Areal SOD k_s ($g/m^2/d$)	0.07-8.0	5*	1.072
Stage-discharge $v=aQ^{x1}$ a		0.062*	
Stage-discharge $v=aQ^{x1}$ x_1		0.4*	
Stage-discharge $d=bQ^{x2}$ b		1.27*	
Stage-discharge $d=bQ^{x2}$ x_2		0.6*	
Background Constituent Concentrations			
T (°C)		8.5	
DO (mg/L)		8.0	
BOD_5 (mg/L)		2.3	
NH_3-N (mg/L)		0.183	

* see Results for explanation of final values used

Table 7-2. Rate Constants and Background Concentrations

Point Source Effluent Flow & Constituent Concentrations	Casselman	Chesterville	Plantagenet	Russell
Q (m^3/s)	0.106	0.086	0	0.056
T (°C)	8.5	8.5	8.5	8.5
DO (mg/L)	4	4	4	4
BOD_5 (mg/L)	30	30	30	30
NH_3-N (mg/L)	14	14	14	14
	Embrum	Maxville	Spencerville	St. Isidore
Q (m^3/s)	0.137	0.017	0.015	0.037
T (°C)	8.5	8.5	8.5	8.5
DO (mg/L)	4	4	4	4
BOD_5 (mg/L)	30	30	30	30
NH_3-N (mg/L)	14	14	14	14
	Williams-burg	Winchester	Ault Winchester	Nestle Chesterville
Q (m^3/s)	0.019	0.182	0.056	0.065
T (°C)	8.5	8.5	8.5	8.5
DO (mg/L)	4	4	4	4
BOD_5 (mg/L)	30	30	30	30
NH_3-N (mg/L)	14	14	14	14

Table 7-3. Point Sources

Initial runs used the default stage-discharge parameters mentioned in the '92 study. In that study HEC-2 was used to determine the flow velocities in the main reaches of the basin, while a global set of stage-discharge parameters was used for the smaller headwaters ($a = 0.072$, $x_1 = 0.4$, $b = 1.27$, $x_2 = 0.6$). To obtain agreement on travel times, velocities determined in HEC-2 were matched in WMDSS and then appropriate values for parameter a were determined. Post-run analysis showed that the global parameters led to stream widths far in excess of physical reality. Stream width was not calculated in the earlier study, and so this result went unnoticed. Parameters were modified to more closely reflect physical reality for stream width and depth while maintaining travel times in main reaches. This necessitated permitting flows in headwaters to increase in velocity from values in the 0.1 m/s range typical of the 1992 study to values in the 0.4 m/s range. It should be noted that most of the headwaters included in this WMDSS analysis were in fact not included in the 1992 study, which used primary water courses, and so the changes do not constitute a significant divergence from the volumetric flow distribution used therein. It does induce a level of in-stream processing above that which takes place in the '92 study, however as is shown in the results report in Figure 7-11 headwaters aerate to levels above background levels, therefore this effect compensates somewhat for the introduction of SOD. This series of changes is but one area where the more complex requirements of the simulation tool QUAL2E over the straight application of the analytical solution to the Streeter-Phelps relation requires a more accurate and comprehensive description of the watershed.

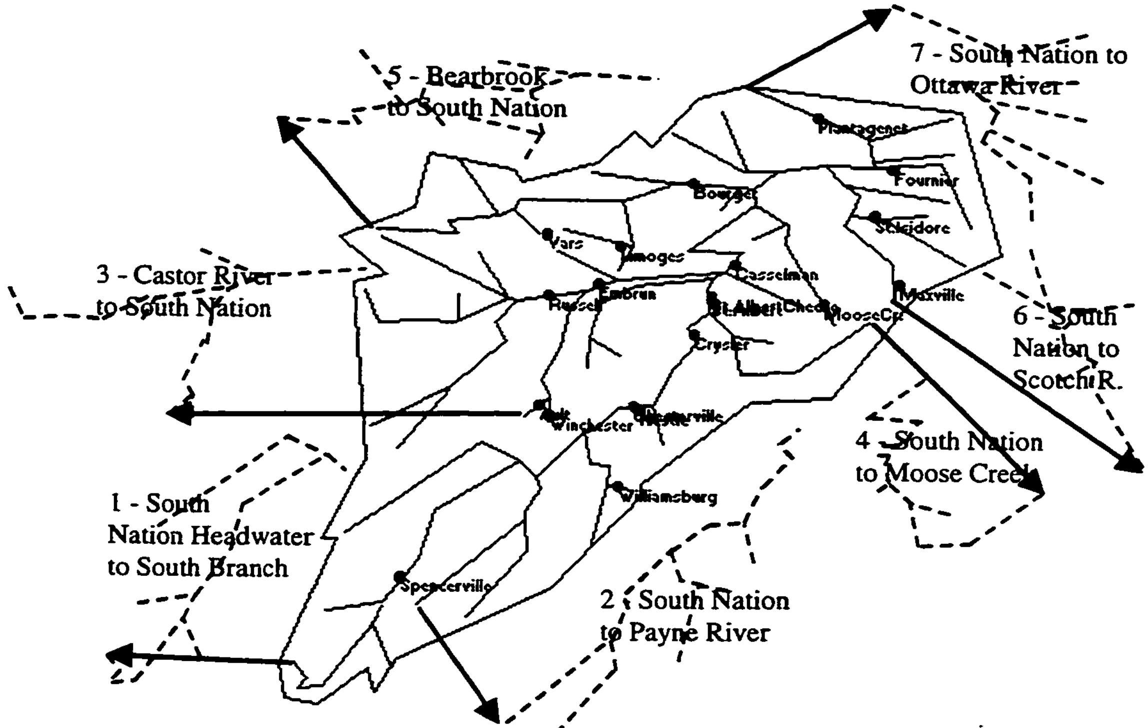


Figure 7-5. WMDSS Stream Network Showing Hydraulic Elements and Point Sources with QUAL2E Input Files #1 to #7

Initial conditions for all stream reaches were as per the 1992 study. The scenario analysed was the spring 30Q20 flow scenario. Background concentrations of DO, BOD and NH_3 were calculated through a straightforward process of eliminating known point source discharges of the constituents from the amounts calculated at Plantagenet near the mouth of the basin and averaging the remainder over the basin. Efforts in the 1992 study to calibrate the water quality model to available in stream measurements proved fruitless. It was determined that this was in part due to the gaps in available data and to the overriding influence of non-point sources on in-stream constituent levels. In the WMDSS analysis, the more comprehensive QUAL2E analysis is assessed on a geographic basis to move towards an understanding of the non-point source problem.

Run 4 - South Nation to Moose Creek Junction

QUAL2E Reach	1	2	3	4	5	6	7	8	9	10	
WMDSS Hw/ReID	hw10,5	re12,37	hw11,11	re13,77	re11,70	re14,96	hw12,48	re16,10	hw15,12	re26,10	
Start (km)	60	48	4	34	4	30	4	24	4	20	
Stop (km)	48	34	0	30	0	24	0	20	0	0	
St.cumul. (km)					53	57		53		49	
Sp.cumul. (km)					49	53		49		45	
Length (km)	12	14	4	4	4	6	4	4	4	20	
# elements	6	7	2	2	2	3	2	2	2	10	
delta x	2	2	2	2	2	2	2	2	2	2	
Qhw (m^3/s)	0.5		0.2		9.23		1		5.34		
Inc.Inf. (m^3/s)		0.2		0.1		0.5				1.4	
Qavg (m^3/s)	0.5	0.6	0.2	0.95	9.23	10.48	1	11.73	5.34	17.84	18.91
DO (mg/L)	10.26	10.0	9.58	9.67	8.23	8.35	7.69	8.17	4.54	6.93	
BOD_u (mg/L)	3.24	2.99	3.24	2.89	2.11	2.08	3.00	1.99	2.03	2.00	
NH_{3t} (mg/L)	0.17	0.15	0.175	0.145	0.195	0.17	0.15	0.155	0.23	0.22	
a	0.88	0.49	0.51	0.3	0.076	0.082	0.076	0.06	0.042	0.051	
x_1	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
b	0.455	0.82	0.79	1.05	0.7	0.65	2.2	0.684	1.05	0.532	
x_2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
vel. (m/s)	0.667	0.40	0.268	0.294	0.185	0.210	0.076	0.161	0.082	0.162	
trvl tm (d)	0.208	0.41	0.173	0.158	0.250	0.331	0.609	0.288	0.564	1.433	
depth (m)	0.300	0.60	0.301	1.018	2.657	2.662	2.200	2.997	2.869	2.998	
width (m)	2.498	2.49	2.482	3.175	18.80	18.76	5.981	24.37	22.68	36.86	

Table 7-4. Summary of a QUAL2E Input File with Parameters and Some Outputs

7.4. QUAL2E Output

Analysis results are shown in Figures 7-6 to 7-10. Figures 7-6 and 7-7 show concentrations of DO/BOD_u and the N family versus distance upstream on the main branch of the South Nation, while Figures 7-8 and 7-9 show the same for the main branch 9f the Castor River upstream of the South Nation junction (the Castor River is QUAL2E run #3).

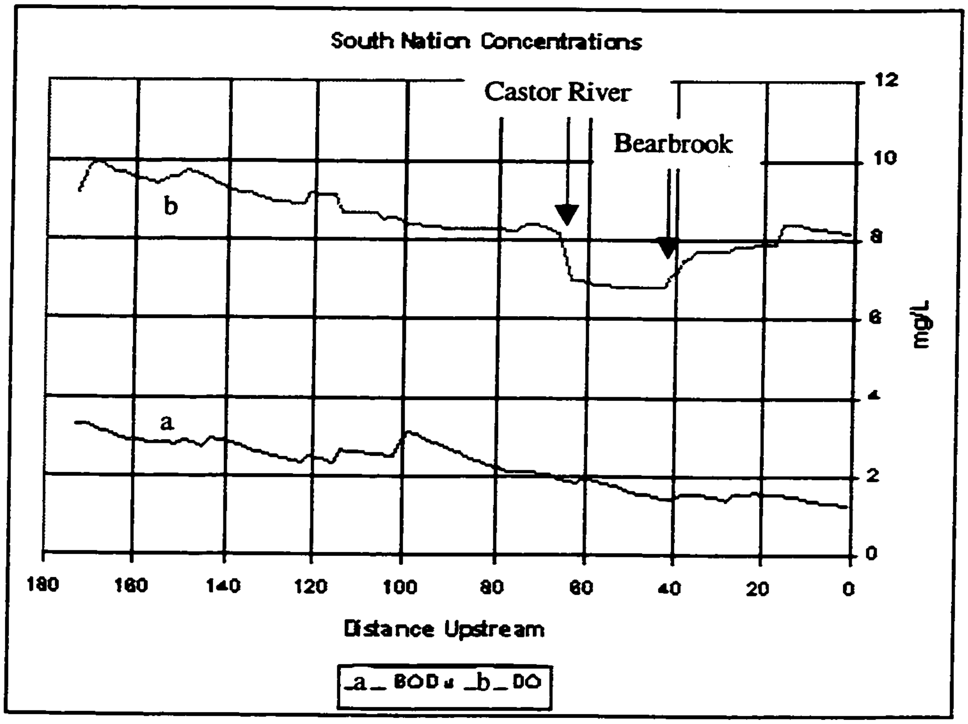


Figure 7-6. DO/BOD_u along Main Branch of the South Nation River

In viewing the results, general observations are that the South Nation main branch DO levels show a gradual fall from mid-headwater highs of 10 mg/L down to 8 mg/L at the mouth, with nearly 2/3 of the BOD being exerted en route. The nitrogen levels show stepped accumulation to the Castor River confluence, and fall thereafter to levels near 0.55 mg/L, 0.4 mg/L, 0.1 mg/L and 0.1 mg/L for sum-N, NO_3, NO_2 and NH_3 respectively. The confluence with the Castor River is marked, especially on N-family levels. The only region with DO levels below 8 mg/L is between the Castor and Bearbrook confluences and on the headwater into which Williamsburg discharges.

The Castor River fairs much worse. This watercourse has a higher width-to-depth ratio than the South Nation and holds some major point source contributors with the city of Embrun on the main branch and the dairy plant Ault and the city of Winchester on the South Castor River. Here assimilative capacity is overrun – DO levels fall to anoxic conditions until the confluence with the main branch of the Castor River, where levels are brought below 6 mg/L and continue to fall until the South Nation confluence.

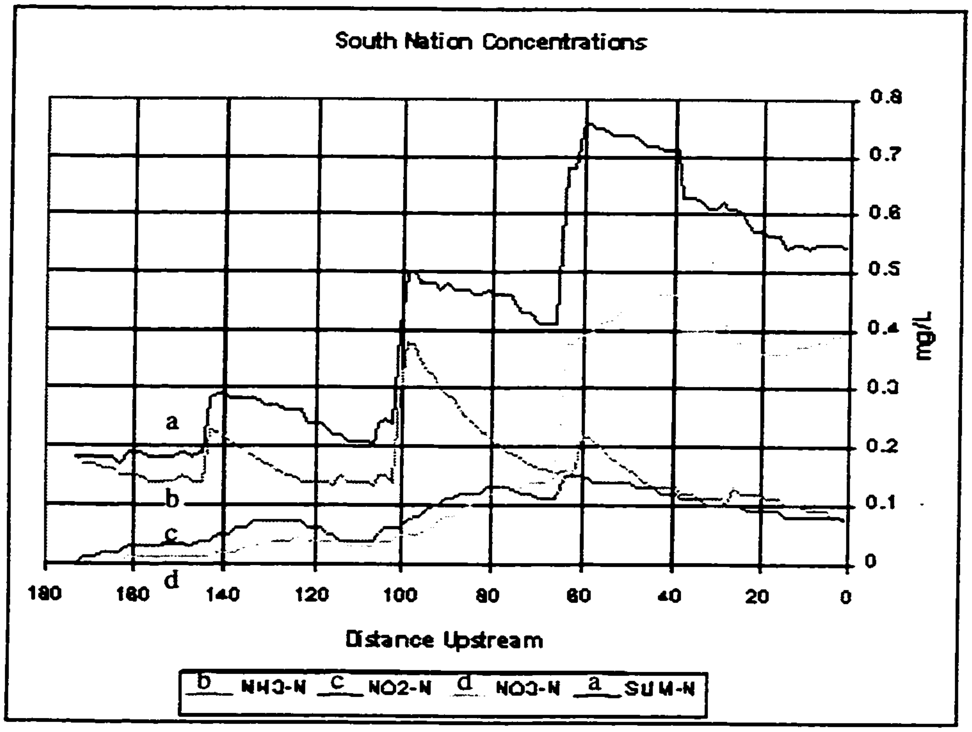


Figure 7-7. N Family along Main Branch of the South Nation River

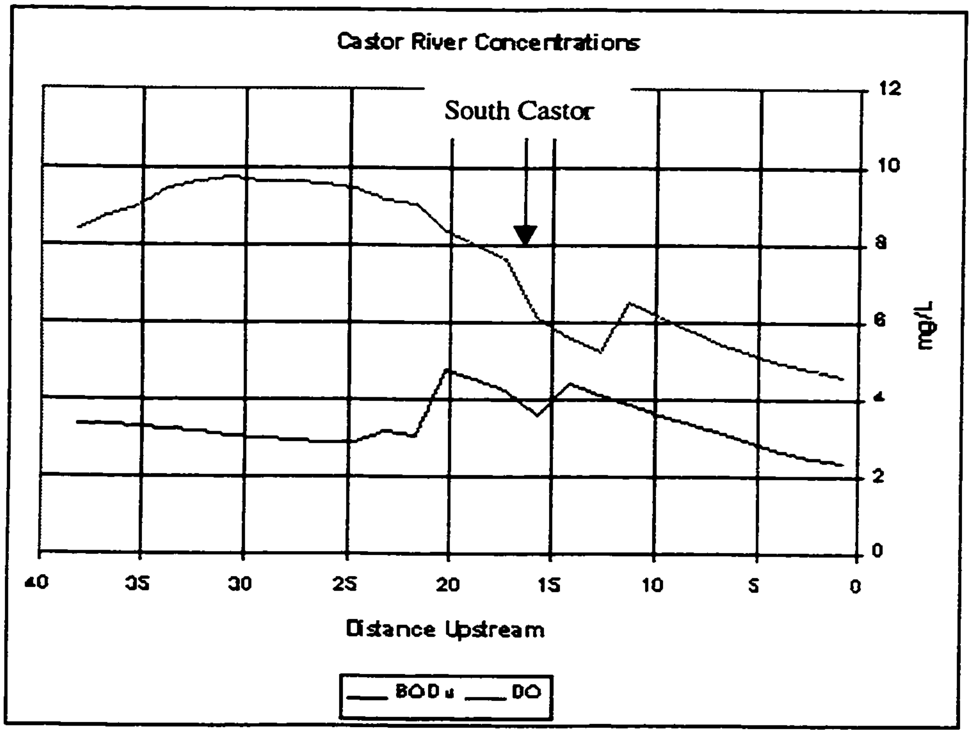


Figure 7-8. DO/BOD_u along Main Branch of the Castor River

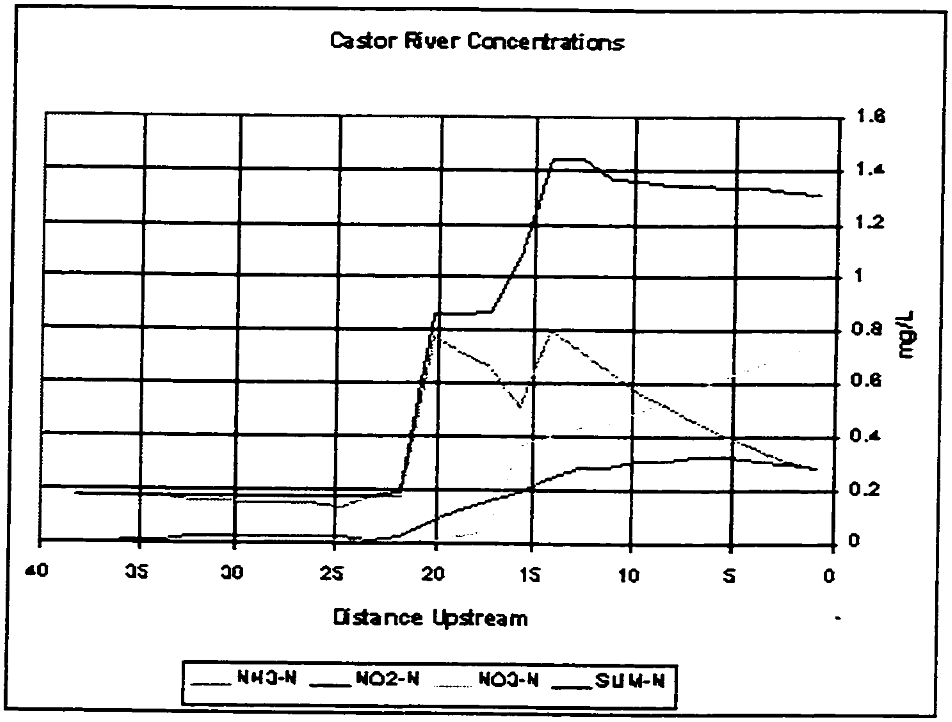


Figure 7-9. N Family along Main Branch of the Castor River

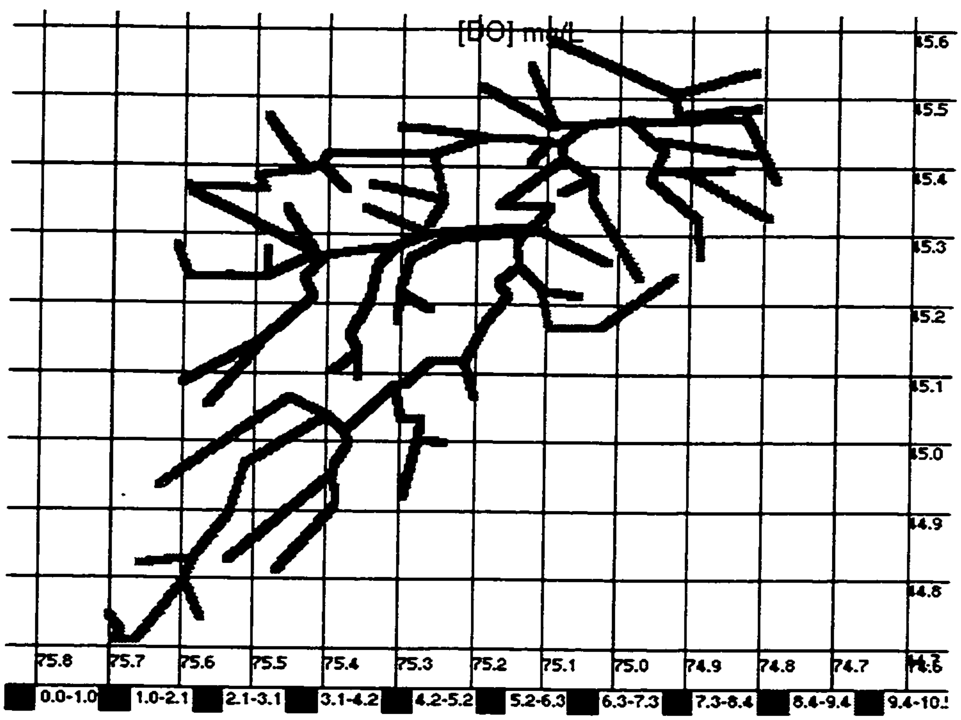


Figure 7-10. WMDSS Report View of the South Nation basin DO Concentrations

7.5. Discussion

7.5.1. In Stream Measurements

Inclusion of a small SOD level has pointed out some areas of concern not identified in the 1992 study. That analysis showed rising DO levels in the South Nation main branch and flat levels along the Castor River. The WMDSS analysis indicates no spare assimilative capacity in the Castor basin and little on the South Nation between the Castor and Bearbrook confluences. With WMDSS, the stream network can be overlaid on an imported vegetation layer to see the open areas being used for intensive agriculture. This is done in Figure 7-11.

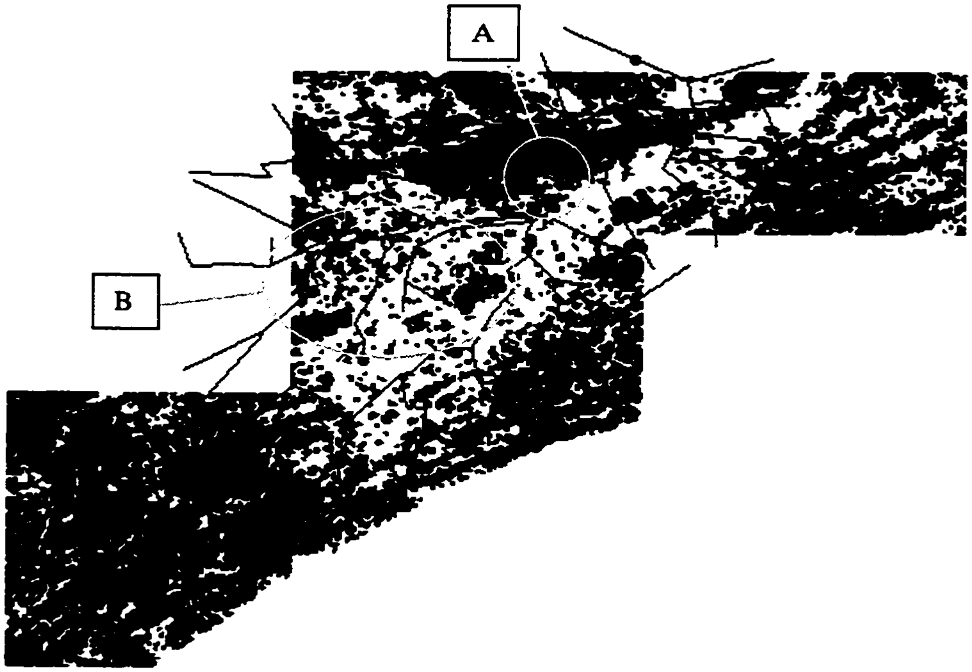


Figure 7-11. WMDSS Map View of the Stream Network Overlaying the Vegetation Theme

Doing this, it is seen that the section of the South Nation south of the Castor River confluence (A) runs through a dense section of forest, and so is likely benefiting from fresh incremental inflows. The Castor basin south of the main branch (B) is part of one of the largest areas in the watershed devoted to agriculture – not shown are the influences on the headwaters of the Castor basin, which also lie in areas of intense agriculture. These findings are reinforced through the fact that efforts currently underway at South Nation

Conservation are focusing on characterising non-point sources along the North Castor reach.

7.6. *Follow-On Work*

Having performed this analysis and validated the efficacy of using WMDSS as a management system for a watershed, further effort is warranted in investigating the magnitude of the non-point source problem in the South Nation basin. The next phase in development of the WMDSS calls for construction of the HEC-RAS interface. This will permit more accurate characterisation of flows in the headwater reaches of the basin under more problematic 7Q20 conditions. A revised analysis should remove assignment of global background levels of non-point source contaminants, instead producing sub-catchment estimates. In this manner, it will be possible to refine determination of areas of concern to the level where calibration of the QUAL2E runs with recent in-stream measurements will be possible, providing a living set of input models for dynamic assessment of constituent concentration levels within the South Nation basin.

7.7. *Summary*

The following summary points are offered:

1. WMDSS offers a tool to provide Integrated Watershed Management (IWM) to water resource users and planners.

2. The QUAL2E interface to WMDSS is validated and demonstrated to be useful in running up to date assessments of surface water quality.

3. The South Nation basin analysis has identified areas of low or no spare assimilative capacity that need refined analysis through characterisation of non-point sources.

4. A thorough assessment of surface water quality requires the use of several modelling tools in tandem such that the shortcomings of one model are compensated by the strengths of another.

5. Identified weaknesses in surface water quality assessment can be compensated for with refinements to time of travel and stream width estimates.

6. Conservative SOD rates have a dramatic impact on stream DO causing violation of DO criteria.

As a final note the authors wish to acknowledge the support of CH2M Gore and Storrie of Ottawa, Ontario for supplying source data on the 1992 Gore and Storrie study of the South Nation basin.

7.8. *Potential for Integrated Watershed Management using WMDSS*

The stated advantage of having access to a comprehensive toolset, while the cornerstone of the WMDSS approach, is by no means the end of its advantages. Because the software permits description of a watershed through a wide range of physical themes, it is possible to examine linkages between themes, a necessary step in integrated watershed management. For example, Figure 7-12 shows the South Nation stream network in WMDSS overlain on an imported bogs/swamps theme. This would permit a manager to see areas offering natural mitigation of anthropogenic contaminants, information that could be useful in formulating decisions on allocation of assimilative capacity for new polluters.

Figure 7-12. WMDSS View of Swamps/Bogs overlain By Hydraulic Elements

This is an exciting feature of the software that should be explored through further research efforts.

7.9. Validation of WMDSS

Successful completion of the QUAL2E analysis validates WMDSS.

Chapter 8. Conclusions

8.1. Current State of Development

In Section 3.5 the list below was used to indicate the critical features of a DSS.

1. Ability to collect information,
2. Ability to formulate models,
3. Ability to govern problems,
4. Ability to analyse problems,
5. Ability to evaluate problems, and
6. Ability to implement strategy.

In reviewing the list, it can be seen that WMDSS assists the manager in most of these tasks. Items 1 is accomplished through turning source data available for the watershed into information within WMDSS by populating the watershed objects with relevant information. Item 2 is accomplished through having access to a suite of modelling tools with functioning interfaces used to generate the input files for their use. Item 3 is accomplished by providing tools for the process lying at the heart of problem scenario analysis. Item 4 is certainly covered through use of the models to analyse problem scenarios and generate assessments of the consequences of solution strategies. Items 5 and 6 are not completely handled by the WMDSS, but are assisted through use of the system. Remembering the aim of designing a manager-in-the-loop system, this is acceptable. The critical ground of providing a link between the geospatially accurate but analytically constrained world of GIS and the geospatially oversimplified but analytically useful world of physical models has been covered by the WMDSS.

Figure 8-1 describes the current state of development of WMDSS as well as describing work left to be done.

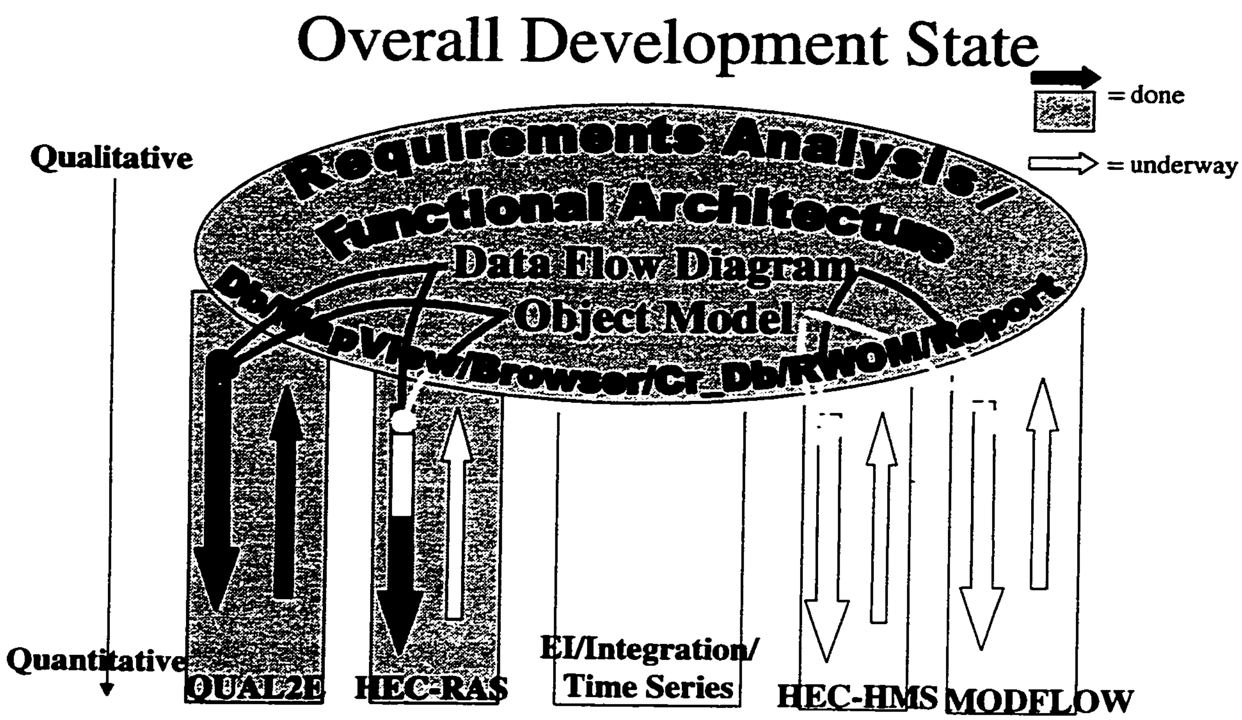


Figure 8-1. Current Development State for WMDSS

As can be seen in Figure 8-1, the foundation for the system has been completed, leaving the remainder of the quantitative analysis arms yet to be completed in the same manner as was done for QUAL2E.

8.2. Future Work

While much has been accomplished herein, there is much left to do. In addition to the completion of the software as outlined in Section 6.13, the following recommendations for future work are offered:

1. <u>Use of WMDSS in Examination of the Non-point Source Problem</u>. The validation analysis points out the importance of extending water quality analysis to treatment of non-point source issues. Indeed, it begins to tackle the problem by permitting users to examine the quality of incremental inflows along a reach by reach basis; this could be used to characterise areas as potential non-point source problems. With the non-point source OM in WMDSS these areas can be broken down into

smaller zones accurately identified by the surface vegetation and soils – couple this with the runoff quality information, and the analysis has begun.

2. Use of WMDSS in Examination of Theme Linkages. See Section 7.3 for details.

3. Use of WMDSS in Creation of Ecological Index. This system is ideally suited to producing an Ecological Index, due to its ability to characterise multiple themes of a watershed both qualitatively and quantitatively.

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Appendix A: User Mail Out

Appendix B: WMDSS Validation South Nation River Dataset

Appendix C: Sample QUAL2E Output File

Appendix A – User Mail Out

UNIVERSITÉ D'OTTAWA • UNIVERSITY OF OTTAWA
Génie • Engineering

8 October 1998

Bob's Consulting Engineers Firm
xxx
Ottawa, ON
xxx xxx

Dear x,

This letter has been sent to you to inform you of a project underway at the University of Ottawa to conduct a detailed requirements capture for use in producing a Decision Support System, aimed for use by water resource users and planners in Eastern Ontario. The enclosed proforma provides an introduction to the project, and solicits your involvement. This project is being undertaken as part of a Master's degree thesis in Environmental Engineering, under the supervision of Dr. Ron Droste.

While recognising the fact that different users will forward different and at times incompatible requirements, it is felt that there is a common user core capability which underlies much of the planning and decision making processes concerning water resources. This project, initiated at the University of Ottawa, is guided by the policies of the Ontario Ministry of Environment and Energy in supporting ecosystem based watershed management approaches, with sustainable use as the overarching mission.

In a climate of reduced budgets and short staffs, the impetus to produce a comprehensive planning and usage tool is stronger than ever. This project, through use of a comprehensive systems analysis methodology, hopes to lay the groundwork for production of a Decision Support System that can compensate for many of the inefficiencies of present day water resource decision making. The cornerstone of this approach is collection of relevant and comprehensive user requirements for such a system. With this in mind, please read the enclosed information and choose to participate in what promises to be a valuable initiative.

David Wilson
Graduate Student
University of Ottawa

enclosure: 1

REQUIREMENTS CAPTURING FOR PRODUCTION OF A DECISION SUPPORT SYSTEM FOR WATER RESOURCE USERS AND PLANNERS IN EASTERN ONTARIO

Introduction

The decisions made by water resource planners and users are frequent, important and carry wide ranging consequences. They often result in changes with impacts over decades, and result in significant expenditures of public and private funds. Providing background and planning assistance to inform those decisions is a time consuming and inexact process. As a result, a significant body of work has focused on the provision of Decision Support Systems (DSS) for water resource planners and users. Today, there is nothing limiting the provision of information technology (IT) based DSS technically; limitations fall rather in the realms of cost and level of production effort.

Production of a DSS will likely pay for itself when the cost is amortized over the future period in which the decision making period is assisted by the DSS, reducing the time and resources which need to be allocated. Under an open architecture methodology, a DSS (if sufficiently user friendly) can be specifically tailored to the needs of municipal and regional planners, growing with the user to embrace new and changing applications. The DSS will need to bring with it a broad and flexible toolset, such that it can accommodate a wide range of potential users. It will also have to contend with a range of data inputs from complete and comprehensive to sparse.

While this growing list of requirements may look unachievable, it must be remembered that a DSS will not in itself have to solve all of the physical problems – it will instead couple together tools, many of them being existing models, which together provide a decision assisting capability. A shortcoming of past initiatives for the provision of DSS has been to enter the problem definition and solution generation process too far into the loop. A detailed understanding of the needs of system users is therefore missed, resulting in an ad hoc approach to solution generation. Rather than trying to fit solutions to problems, the problems must be thoroughly defined through a requirements analysis. This approach is best suited to a systems analysis methodology, reinforced by the mapping of user needs onto an IT solution architecture. The steps in such a systems analysis are as follows:

1. Define Process Inputs (Both Physical and Non-physical)
2. Perform Systems Analysis
   (a) Analyse User Requirements
   (b) Map Requirements to Functions
   (c) Synthesize Functions
3. Define Process Outputs (Decision Support)
4. Characterise Physical Problem Space (Physical Boundary Conditions)

Aim

The aim of this mail out is to solicit user support in capturing the requirements for a Decision Support System, and to provide an opportunity to become involved in the project.

Format for Responses

There is a proforma that follows, which may be filled out and returned to the address listed at the end. Alternatively, participants can complete their returns electronically and submit them by e-mail to the indicated address – the electronic copy of the proforma is available at http://ourworld.compuserve.com/homepages/Dave_J_Wilson

User Requirements

A. Respondent Particulars

Last name		First name		Init.	
Position		Address			
Phone		Fax		E-mail	
Position responsibilities:					
Do you work singly, or as part of a staff?				singly	part of staff
If part of a staff, how many are on the staff?	2-3	4-5	6-10	11+	
Would you like to have a meeting with the project team concerning participation in this effort?				y	n
Would you like to be kept abreast of development in the follow-on stages of this project?				y	n

B. Water Resource Planning

Have you (or your organisation) ever participated in the production of a watershed management plan?	y	n

If so, what was your responsibility?		
If so, what IT tools (if any) did you use to assist you?		
Do you know of IT tools or models available for use in water resource planning?	y	n
If so, would you please describe them:		

If you could design a decision support system for use in water resources planning, which of the following criteria would you consider important, and to what degree?

Criteria	Very -------- Not very	n/a
tools and information to support remediation measures planning	1 2 3 4 5	
tools and information to support water quality protection planning	1 2 3 4 5	
tools and information to support water quantity protection planning	1 2 3 4 5	
tools and information to support watershed analysis integration measures	1 2 3 4 5	
tools and information to support resource economic quantification analysis	1 2 3 4 5	
Others? Please specify	Very -------- Not very	n/a
	1 2 3 4 5	
	1 2 3 4 5	
	1 2 3 4 5	

Comments on section B:

C. Water Resource Decision Making

Have you (or your organisation) ever participated in a water resources decision making process (eg. determining changes to point source outfall lavels, determining flow adjustment/allocation between users, etc.)?	y	n
If so, what was your responsibility?		
If so, what IT tools (if any) did you use to assist you?		
Do you know of IT tools or models available for use in water resource decision making?	y	n
If so, would you please describe them:		

If you could design a decision support system for use in water resources decision making, which of the following criteria would you consider important, and to what degree?

Criteria	Very -------- Not very	n/a
tools and information to allocate water withdrawals fairly amongst users	1 2 3 4 5	
tools and information to project the impact of new withdrawals on existing users	1 2 3 4 5	
tools and information to assess the impact of changes to rainfall/ runoff imputs	1 2 3 4 5	

tools and information to assess the impact of changes in graoundwater flows/levels	1 2 3 4 5	
tools and information to support cost-based comparisons	1 2 3 4 5	
Others? Please specify	Very -------- Not very	n/a
	1 2 3 4 5	
	1 2 3 4 5	
	1 2 3 4 5	

Comments on section C:

D. Physical Modelling/Analysis Tools

List the physical modelling/analysis tools that you have used (eg. HEC, OTTHYMO, AGNPS), along with their particulars:

Model Name	Purpose (circle applicable)	Source	Utility (ie. how well did it meet the requirement?)
	Water quantity Other (specify) Water quality Planning Optimisation		
	Water quantity Other (specify) Water quality Planning Optimisation		
	Water quantity Other (specify) Water quality Planning Optimisation		

Are there physical phenomena (eg. runoff, groundwater flow) which you would like to be able to model but currently cannot?	y	n

If so, please describe:

Do you employ GIS in your water resource work?	y	n
If so, how, and what package are you using?		
Comments on section D:		

E. General Comments

Contact Information

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P.O. Box 450, Stn. A
Ottawa, ON
K1N 6N5

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Appendix B – WMDSS Validation South Nation River Dataset

HyElID	Start Loc X	Start Loc Y	Start L	End Loc X	End Loc Y	End L	Vol_Flow	Temp	Conc_DO	Conc_BOD	NH3	ReID	HwID	ReElID	LWID	JcnID
1	74.79213	45.324558	111	74.90435	45.39085	56	0.3	8.5	8	3.37	0.182		35			33
2	75.698631	44.743759	108	75.68259	44.72071	103	0.3	8.5	8	3.37	0.182		1			1
3	75.682587	44.720711	103	75.69426	44.7063	100	0.5	8.5	8	3.37	0.182	1		1		1
4	74.783386	45.379318	101	74.82274	45.473	61	0.2	8.5	8	3.37	0.182		39			36
5	74.921837	45.240971	100	75.02094	45.16891	80	0.3	8.5	8	3.37	0.182		10			10
6	75.633049	44.93256	100	75.45087	45.06371	80	0.5	8.5	8	3.37	0.182		4			3
7	75.659279	44.820141	100	75.5835	44.83023	91	0.5	8.5	8	3.37	0.182		3			2
8	75.69426	44.706299	100	75.66219	44.71062	98	0.6	8.5	8	3.37	0.182	1		2		1
9	75.662193	44.710621	98	75.59515	44.79853	92	0.8	8.5	8	3.37	0.182	1		3		1
10	75.570381	44.740879	97	75.59515	44.79853	92	0.2	8.5	8	3.37	0.182		2			1
11	75.051537	45.210701	96	75.10547	45.21935	66	0.1	8.5	8	3.37	0.182		11			10
12	75.609734	45.282761	95	75.59224	45.23809	93	0.3	8.5	8	3.37	0.182		15			14
13	74.967018	45.238091	95	75.03551	45.35338	68	0.1	8.5	8	3.37	0.182		24			22
14	75.012199	45.259701	94	75.11567	45.31303	52	0.4	8.5	8	3.37	0.182		14			13
15	75.592239	45.238091	93	75.5354	45.24097	89	0.5	8.5	8	3.37	0.182	17		1		14
16	75.595154	44.798531	92	75.5835	44.82879	91	1.1	8.5	8	3.37	0.182	2		1		2
17	75.583504	44.830231	91	75.53394	44.89653	89	1.9	8.5	8	3.37	0.182	3		1		3
18	74.886864	45.269791	91	74.88832	45.32312	81	0.2	8.5	8	3.37	0.182		37			33
19	75.481483	45.278439	90	75.48293	45.23953	86	0.2	8.5	8	3.37	0.182		16			14
20	75.533943	44.89653	89	75.51208	44.96426	82	2.2	8.5	8	3.37	0.182	3		2		3
21	75.5354	45.240971	89	75.48148	45.23809	86	0.7	8.5	8	3.37	0.182	17		2		14
22	75.466904	44.811501	88	75.38675	44.90806	77	0.5	8.5	8	3.37	0.182		6			5
23	75.536858	44.827351	88	75.38966	44.95417	76	0.5	8.5	8	3.37	0.182		5			5
24	75.482933	45.239529	86	75.41589	45.27267	69	1	8.5	8	3.37	0.182	18		1		15
25	75.29493	44.91959	86	75.27453	45.00462	80	0.2	8.5	8	3.37	0.182		7			7
26	75.481483	45.473	83	75.43047	45.39373	68	0.3	8.5	8	3.37	0.182		27			24
27	75.239548	44.995972	82	75.27453	45.00317	80	0.5	8.5	8	3.37	0.182		8			7
28	75.593697	45.37212	82	75.48585	45.36635	70	0.3	8.5	8	3.37	0.182		26			30
29	75.589317	45.36203	82	75.49605	45.31591	76	0.3	8.5	8	3.37	0.182		17			15
30	75.512077	44.96426	82	75.39841	45.03632	75	2.6	8.5	8	3.37	0.182	3		3		3
31	74.888321	45.32312	81	74.95682	45.38221	55	0.4	8.5	8	3.37	0.182	41		1		34
32	75.450867	45.063709	80	75.39841	45.03632	75	0.9	8.5	8	3.37	0.182	4		1		3
33	75.600983	45.08532	80	75.49022	45.14441	76	0.5	8.5	8	3.37	0.182		20			17
34	75.564552	45.053619	80	75.49022	45.14297	76	0.5	8.5	8	3.37	0.182		19			17
35	75.274529	45.00317	80	75.27307	45.032	77	0.8	8.5	8	3.37	0.182	9		1		6
36	75.200203	45.063709	80	75.21478	45.11703	68	0.5	8.5	8	3.37	0.182		9			8
37	75.020943	45.168911	80	75.09381	45.16603	76	0.4	8.5	8	3.37	0.182	12		1		10
38	75.259956	45.191971	77	75.30222	45.21791	69	0.3	8.5	8	3.37	0.182		13			12
39	75.386749	44.908058	77	75.38966	44.95417	76	0.6	8.5	8	3.37	0.182	6		1		5
40	75.273071	45.032001	77	75.2993	45.03344	73	0.9	8.5	8	3.37	0.182	9		2		6
41	75.389664	44.95417	76	75.38821	44.96571	75	1.2	8.5	8	3.37	0.182	7		1		4
42	75.490219	45.144409	76	75.41881	45.21215	73	1.3	8.5	8	3.37	0.182	21		1		16
43	75.496048	45.31591	76	75.41589	45.27267	69	0.4	8.5	8	3.37	0.182	19		1		15
44	75.093811	45.166031	76	75.10547	45.22223	66	0.7	8.5	8	3.37	0.182	12		2		10

115 j

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45	75.388206	44.96571	75	75.3678	44.99597	74	1.4	8.5	8	3.37	0.182	7		2		4
46	75.398407	45.03632	75	75.37363	45.01326	73	3.8	8.5	8	3.37	0.182	5		1		4
47	75.456703	45.33897	75	75.41589	45.27267	69	0.1	8.5	8	3.37	0.182		18			15
48	75.303673	45.174671	75	75.30222	45.21791	69	0.3	8.5	8	3.37	0.182		12			12
49	75.367798	44.995972	74	75.37363	45.01326	73	2	8.5	8	3.37	0.182	7		3		4
50	75.418808	45.212151	73	75.43338	45.23809	70	1.6	8.5	8	3.37	0.182	21		2		16
51	75.373627	45.01326	73	75.30659	45.081	69.5	6.5	8.5	8	3.37	0.182	8		1		6
52	75.299301	45.03344	73	75.30659	45.081	69.5	1.1	8.5	8	3.37	0.182	9		3		6
53	75.391121	45.101181	71	75.3576	45.13	70.5	0.1	8.5	8	3.37	0.182		22			19
54	75.35614	45.093971	71	75.3576	45.13	70.5	0.1	8.5	8	3.37	0.182		21			19
55	75.357597	45.130001	70.5	75.3678	45.15594	70	0.4	8.5	8	3.37	0.182	23		1		18
56	75.485847	45.366348	70	75.49751	45.38653	69.5	0.4	8.5	8	3.37	0.182	30		1		24
57	75.43338	45.238091	70	75.40424	45.26979	68	2	8.5	8	3.37	0.182	21		3		16
58	75.373627	45.366348	70	75.41006	45.40382	67	0.3	8.5	8	3.37	0.182		28			25
59	75.300758	45.45715	70	75.19146	45.44273	49	0.3	8.5	8	3.37	0.182		31			27
60	75.348846	45.340408	70	75.26433	45.3015	60	0.2	8.5	8	3.37	0.182		23			20
61	75.367798	45.155941	70	75.34157	45.2035	69.5	0.6	8.5	8	3.37	0.182	23		2		18
62	75.497513	45.386532	69.5	75.43047	45.39373	68	0.6	8.5	8	3.37	0.182	30		2		24
63	75.306587	45.081001	69.5	75.29202	45.08388	69.25	7.2	8.5	8	3.37	0.182	10		1		8
64	75.341568	45.203499	69.5	75.32991	45.25826	67	0.8	8.5	8	3.37	0.182	23		3		18
65	75.292023	45.083881	69.25	75.25996	45.11559	68.75	7.3	8.5	8	3.37	0.182	10		2		8
66	75.302223	45.217911	69	75.28619	45.26691	64	0.6	8.5	8	3.37	0.182	15		1		11
67	75.415894	45.272671	69	75.40424	45.26979	68	1.5	8.5	8	3.37	0.182	20		1		16
68	75.259956	45.115589	68.75	75.21478	45.11703	68	7.7	8.5	8	3.37	0.182	10		3		8
69	75.404243	45.269791	68	75.30659	45.28421	62	3.6	8.5	8	3.37	0.182	22		1		18
70	75.214783	45.117031	68	75.18271	45.17467	60	8.3	8.5	8	3.37	0.182	11		1		9
71	75.035507	45.353378	68	75.0326	45.38221	60	0.1	8.5	8	3.37	0.182	27		1		22
72	75.430473	45.39373	68	75.40861	45.40382	67	1	8.5	8	3.37	0.182	31		1		25
73	75.410057	45.40382	67	75.39986	45.41679	66	1.3	8.5	8	3.37	0.182	32		1		26
74	75.32991	45.258259	67	75.30659	45.28421	64	1	8.5	8	3.37	0.182	23		4		18
75	75.399857	45.41679	66	75.25704	45.41824	56	2	8.5	8	3.37	0.182	32		2		26
76	74.815437	45.41679	66	74.95682	45.44129	47	0.2	8.5	8	3.37	0.182		38			35
77	75.105469	45.222229	66	75.13608	45.25538	58	1	8.5	8	3.37	0.182	13		1		9
78	75.286186	45.266911	64	75.23955	45.29285	59	0.8	8.5	8	3.37	0.182	15		2		11
79	74.84314	45.396622	64	74.90435	45.39085	56	0.1	8.5	8	3.37	0.182		36			33
80	75.306587	45.28421	64	75.26433	45.3015	60	4.6	8.5	8	3.37	0.182	24		1		20
81	75.338654	45.373562	63	75.24392	45.3505	60	0.3	8.5	8	3.37	0.182		30			27
82	75.262871	45.31591	63	75.24392	45.3505	60	0.3	8.5	8	3.37	0.182		29			27
83	74.809624	45.487411	62	74.91747	45.47444	45.6	0.2	8.5	8	3.37	0.182		40			37
84	75.079239	45.36203	62	75.03406	45.38221	60	0.1	8.5	8	3.37	0.182		25			22
85	75.122963	45.546501	62	75.08798	45.46003	48	0.3	8.5	8	3.37	0.182		34			31
86	74.822739	45.473	45.8	74.91601	45.46579	45.7	0.4	8.5	8	3.37	0.182	45		1		36
87	75.122963	45.405258	61	75.09673	45.43841	47	0.1	8.5	8	3.37	0.182		32			29
88	75.182709	45.174671	60	75.15211	45.21215	59	8.4	8.5	8	3.37	0.182	11		2		9
89	75.264328	45.301498	60	75.11567	45.31303	52	5	8.5	8	3.37	0.182	25		1		13

90	75.0326	45.38221	60	75.07632	45.41103	48	0.2	8.5	8	3.37	0.182	28		1		21
91	75.243919	45.350498	60	75.25704	45.41824	56	0.9	8.5	8	3.37	0.182	33		1		26
92	75.239548	45.29285	59	75.13171	45.30438	54	1	8.5	8	3.37	0.182	15		3		11
93	75.189987	45.516239	59	75.08798	45.45715	48	0.3	8.5	8	3.37	0.182		33			31
94	75.152107	45.212151	59	75.16522	45.23088	58.5	8.4	8.5	8	3.37	0.182	11		3		9
95	75.165222	45.230881	58.5	75.13608	45.25538	58	9	8.5	8	3.37	0.182	11		4		9
96	75.136078	45.255379	58	75.13899	45.28997	56	10	8.5	8	3.37	0.182	14		1		11
97	74.812531	45.539291	56	74.92038	45.50759	45.5	0.2	8.5	8	3.37	0.182		41			38
98	75.138992	45.28997	56	75.13171	45.30438	54	11	8.5	8	3.37	0.182	14		2		11
99	75.257042	45.41824	56	75.18999	45.44129	49	2.9	8.5	8	3.37	0.182	34		1		28
100	74.90435	45.39085	56	74.94807	45.39806	52	0.6	8.5	8	3.37	0.182	40		1		34
101	74.956818	45.38221	55	74.94807	45.39806	52	0.4	8.5	8	3.37	0.182	41		2		35
102	75.131706	45.304379	54	75.11567	45.31447	52	12	8.5	8	3.37	0.182	16		1		13
103	75.115669	45.31303	52	75.09381	45.34185	50	17.4	8.5	8	3.37	0.182	26		1		21
104	74.948067	45.39806	52	74.93641	45.42544	49	1	8.5	8	3.37	0.182	42		1		35
105	75.093811	45.34185	50	75.16522	45.34329	49	18	8.5	8	3.37	0.182	26		2		21
106	75.165222	45.343288	49	75.07632	45.41103	48	18.8	8.5	8	3.37	0.182	26		3		21
107	74.936409	45.425442	49	74.95536	45.44129	47	1.2	8.5	8	3.37	0.182	42		2		35
108	75.19146	45.44273	49	75.09673	45.43841	47	3.5	8.5	8	3.37	0.182	35		1		29
109	75.087982	45.46003	48	75.04717	45.46003	46.3	0.6	8.5	8	3.37	0.182	38		1		30
110	75.076317	45.41103	48	75.07778	45.43553	47	19	8.5	8	3.37	0.182	29		1		23
111	74.956818	45.441292	47	74.98159	45.47012	46	1.4	8.5	8	3.37	0.182	43		1		32
112	75.096733	45.438412	47	75.07778	45.43553	46.5	3.6	8.5	8	3.37	0.182	36		1		23
113	75.077782	45.435532	46.5	75.04717	45.46003	46.3	22.6	8.5	8	3.37	0.182	37		1		30
114	75.047173	45.46003	46.3	74.98159	45.47012	46	24.4	8.5	8	3.37	0.182	39		1		32
115	74.98159	45.470119	46	74.91601	45.46579	45.7	25.8	8.5	8	3.37	0.182	44		1		36
116	74.916008	45.46579	45.7	74.91747	45.47444	45.6	26.2	8.5	8	3.37	0.182	46		1		37
117	74.917473	45.474442	45.6	74.92329	45.50903	45.5	26.6	8.5	8	3.37	0.182	47		1		38
118	74.92038	45.507591	45.5	75.09235	45.58541	45	28.3	8.5	8	3.37	0.182	48		1		0

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PtSrceID	Loc X	Loc Y	Loc Z	Name	Vol_Flow	Temp	Conc_DO	Conc_BO	NH3	HyElID
1	75.55872	44.86771	90	Spencerville	0.015	8.5	4	43.9	14	17
2	75.35614	45.10262	71	Winchester	0.182	8.5	4	43.9	14	54
3	75.241	45.11847	68.5	Chesterville	0.086	8.5	4	43.9	14	68
4	75.25996	45.00174	81	Williamsburg	0.019	8.5	4	43.9	14	27
5	75.23226	45.11271	68.5	Nestle	0.065	8.5	4	43.9	14	68
6	75.15794	45.22223	58.4	Crysler	0	8.5	4	43.9	14	94
7	75.13316	45.27123	58	St.Albert	0	8.5	4	43.9	14	95
8	75.13316	45.27844	57.8	St.AlbertCheese	0	8.5	4	43.9	14	95
9	75.37217	45.11847	71	Ault	0.056	8.5	4	43.9	14	53
10	75.36051	45.27844	67	Russell	0.056	8.5	4	43.9	14	69
11	75.29056	45.29429	63	Embrun	0.137	8.5	4	43.9	14	80
12	75.1011	45.32456	51	Casselman	0.106	8.5	4	43.9	14	102
13	74.98159	45.26691	83	MooseCr.	0	8.5	4	43.9	14	13
14	74.87957	45.29573	87	Maxville	0.017	8.5	4	43.9	14	18
15	74.91601	45.39518	55	St.Isidore	0.037	8.5	4	43.9	14	98
16	75.16085	45.44273	48.7	Bourget	0	8.5	4	43.9	14	107
17	75.26141	45.3505	61	Limoges	0	8.5	4	43.9	14	81
18	75.36343	45.36635	70	Vars	0	8.5	4	43.9	14	89
19	74.88978	45.46291	50	Fournier	0	8.5	4	43.9	14	115
20	74.99471	45.53785	45.25	Plantagenet	0	8.5	4	43.9	14	118

Appendix C – Sample QUAL2E Output File

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* * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
                                        Version 3.21  -  Feb. 1995
    $$$ (PROBLEM TITLES) $$$

   CARD TYPE                       QUAL-2E PROGRAM TITLES
   TITLE01            SNatCasselman
   TITLE02
   TITLE03  YES       CONSERVATIVE MINERAL I        Cl IN mg/L
   TITLE04  YES       CONSERVATIVE MINERAL II       Fe IN mg/L
   TITLE05  YES       CONSERVATIVE MINERAL III      Br IN mg/L
   TITLE06  YES       TEMPERATURE
   TITLE07  YES       BIOCHEMICAL OXYGEN DEMAND
   TITLE08  NO        ALGAE AS CHL-A IN UG/L
   TITLE09  NO        PHOSPHORUS CYCLE AS P IN MG/L
   TITLE10              (ORGANIC-P; DISSOLVED-P)
   TITLE11  YES       NITROGEN CYCLE AS N IN MG/L
   TITLE12              (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
   TITLE13  YES       DISSOLVED OXYGEN IN MG/L
   TITLE14  NO        FECAL COLIFORM IN NO./100 ML
   TITLE15  NO        ARBITRARY NON-CONSERVATIVE
   ENDTITLE

   $$$ DATA TYPE 1 (CONTROL DATA) $$$

   CARD TYPE                                  CARD TYPE
   LIST DATA INPUT                0.00000                                 0.00000
   NO WRITE OPTIONAL SUMMARY      0.00000                                 0.00000
   NO FLOW AUGMENTATION           0.00000                                 0.00000
   STEADY STATE                   0.00000                                 0.00000
   NO TRAP CHANNELS               0.00000                                 0.00000
   PRINT LCD/SOLAR DATA           0.00000                                 0.00000
   PLOT DO AND BOD DATA           0.00000                                 0.00000
   FIXED DNSTM CONC (YES=1)=      0.00000     5D-ULT BOD CONV K COEF  =   0.23000
   INPUT METRIC            =      1.00000     OUTPUT METRIC           =   1.00000
   NUMBER OF REACHES       =     10.00000     NUMBER OF JUNCTIONS     =   4.00000
   NUM OF HEADWATERS       =      5.00000     NUMBER OF POINT LOADS   =   2.00000
   TIME STEP (HOURS)       =      0.00000     LNTH. COMP. ELEMENT (DX)=   2.00000
   MAXIMUM ROUTE TIME (HRS)=     30.00000     TIME INC. FOR RPT2 (HRS)=   0.00000
   LATITUDE OF BASIN (DEG) =     45.13000     LONGITUDE OF BASIN (DEG)=  75.19000
   STANDARD MARIDIAN (DEG) =     75.00000     DAY OF YEAR START TIME  = 100.00000
   EVAP. COEF.,(AE)        =      0.00000     EVAP. COEF.,(BE)        =   0.00001
   ELEV. OF BASIN (ELEV)   =     71.10000     DUST ATTENUATION COEF.  =   0.13000
   ENDATA1                        0.00000                                 0.00000

   $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$
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CARD TYPE                                              CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=     3.5000           O UPTAKE BY NO2 OXID(MG O/MG N)=     1.0000
O PROD  BY ALGAE (MG O/MG A)    =    1.6000           O UPTAKE BY ALGAE (MG O/MG A)   =    2.0000
N CONTENT OF ALGAE (MG N/MG A)  =    0.0850           P CONTENT OF ALGAE (MG O/MG A)  =    0.0120
ALG MAX SPEC GROWTH RATE(1/DAY)=     1.3070           ALGAE RESPIRATION RATE (1/DAY)  =    0.1500
N HALF SATURATION CONST (MG/L)  =    0.2000           P HALF SATURATION CONST (MG/L)  =    0.0300
LIN ALG SHADE CO (1/M-UGCHA/L)  =    0.0027           NLIN SHADE (1/M-(UGCHA/L)**2/3)=     0.0165
LIGHT FUNCTION OPTION (LFNOPT)  =    1.0000           LIGHT SAT'N COEF (LANGLEYS/MIN)=     0.0300
DAILY AVERAGING OPTION (LAVOPT)=     1.0000           LIGHT AVERAGING FACTOR (AFACT)  =    0.9200
NUMBER OF DAYLIGHT HOURS (DLH)  =    0.0000           TOTAL DAILY SOLR RAD (LANGLEYS)=     0.0000
ALGY GROWTH CALC OPTION(LGROPT)=     1.0000           ALGAL PREF FOR NH3-N (PREFN)    =    0.5000
ALG/TEMP SOLR RAD FACTOR(TFACT)=     0.4500           NITRIFICATION INHIBITION COEF   =   10.0000
ENDATA1A                             0.0000                                                0.0000

$$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE      RATE CODE      THETA VALUE

THETA( 1)       BOD DECA        1.047     USER
THETA( 2)       BOD SETT        1.024     USER
THETA( 3)       OXY TRAN        1.024     USER
THETA( 4)       SOD RATE        1.060     USER
THETA( 5)       ORGN DEC        1.047     USER
THETA( 6)       ORGN SET        1.024     USER
THETA( 7)       NH3 DECA        1.083     USER
THETA( 8)       NH3 SRCE        1.074     USER
THETA( 9)       NO2 DECA        1.047     USER
THETA(10)       PORG DEC        1.047     DFLT
THETA(11)       PORG SET        1.024     DFLT
THETA(12)       DISP SRC        1.074     DFLT
THETA(13)       ALG GROW        1.047     DFLT
THETA(14)       ALG RESP        1.047     DFLT
THETA(15)       ALG SETT        1.024     DFLT
THETA(16)       COLI DEC        1.047     DFLT
THETA(17)       ANC DECA        1.000     DFLT
THETA(18)       ANC SETT        1.024     DFLT
THETA(19)       ANC SRCE        1.000     DFLT
ENDATA1B

$$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE            REACH ORDER AND IDENT                 R. MI/KM          R. MI/KM
STREAM REACH     1.0  RCH=  Hw10 HyE1ID  5    FROM          60.0    TO        48.0
STREAM REACH     2.0  RCH=  Re12 HyE1ID  37   FROM          48.0    TO        34.0
STREAM REACH     3.0  RCH=  Hw11 HyE1ID  11   FROM           4.0    TO         0.0
STREAM REACH     4.0  RCH=  Re13 HyE1ID  77   FROM          34.0    TO        30.0
STREAM REACH     5.0  RCH=  Re11 HyE1ID  70   FROM           4.0    TO         0.0
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STREAM REACH      6.0  RCH= Re14 HyElID  96   FROM      30.0   TO      24.0
STREAM REACH      7.0  RCH= Hw12 HyElID  48   FROM       4.0   TO       0.0
STREAM REACH      8.0  RCH= Re16 HyElID  10   FROM      24.0   TO      20.0
STREAM REACH      9.0  RCH= Hw15 HyElID  12   FROM       4.0   TO       0.0
STREAM REACH     10.0  RCH= Re26 HyElID  10   FROM      20.0   TO       0.0
ENDATA2           0.0                                    0.0            0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                    REACH  AVAIL HDWS TARGET    ORDER OF AVAIL SOURCES
ENDATA3                        0.         0.       0.0  0.  0.   0.   0.   0.   0.

 $$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE        REACH ELEMENTS/REACH          COMPUTATIONAL FLAGS
FLAG FIELD         1.        6.        1.2.2.2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         2.        7.        2.2.2.2.2.2.3.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         3.        2.        1.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         4.        2.        4.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         5.        2.        1.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         6.        3.        4.6.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         7.        2.        1.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         8.        2.        4.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD         9.        2.        1.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD        10.       10.        4.2.6.2.2.2.2.2.2.5.0.0.0.0.0.0.0.0.0.0.
ENDATA4            0.        0.        0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

 $$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE        REACH  COEF-DSPN  COEFQV   EXPOQV   COEFQH   EXPOQH   CMANN
HYDRAULICS         1.    100.00    0.880    0.400    0.455    0.600    0.040
HYDRAULICS         2.    100.00    0.490    0.400    0.820    0.600    0.040
HYDRAULICS         3.    100.00    0.510    0.400    0.790    0.600    0.040
HYDRAULICS         4.    100.00    0.300    0.400    1.050    0.600    0.040
HYDRAULICS         5.    100.00    0.076    0.400    0.700    0.600    0.040
HYDRAULICS         6.    100.00    0.082    0.400    0.650    0.600    0.040
HYDRAULICS         7.    100.00    0.076    0.400    2.200    0.600    0.040
HYDRAULICS         8.    100.00    0.060    0.400    0.684    0.600    0.040
HYDRAULICS         9.    100.00    0.042    0.400    1.050    0.600    0.040
HYDRAULICS        10.    100.00    0.051    0.400    0.532    0.600    0.040
ENDATA5            0.      0.00    0.000    0.000    0.000    0.000    0.000

 $$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE                          DUST    CLOUD   DRY BULB  WET BULB     ATM               SOLAR RAD
                REACH  ELEVATION   COEF    COVER     TEMP      TEMP     PRESSURE   WIND   ATTENUATION
TEMP/LCD          1.     71.10     0.13     0.25     8.50      8.00      980.00    0.00       1.00
```

TEMP/LCD	2.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	3.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	4.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	5.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	6.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	7.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	8.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	9.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
TEMP/LCD	10.	71.10	0.13	0.25	8.50	8.00	980.00	0.00	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 OR TSIV COEF OR FOR OPT 8	EXPQK2 SLOPE FOR OPT 8
REACT COEF	1.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	2.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	3.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	4.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	5.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	6.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	7.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	8.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	9.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
REACT COEF	10.	0.50	0.00	1.000	3.	0.80	0.000	0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000	0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	2.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	3.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	4.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	5.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	6.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	7.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	8.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	9.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
N AND P COEF	10.	0.00	0.00	1.00	0.00	1.00	0.00	0.25	0.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC

ALG/OTHER COEF	1.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	2.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	3.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	4.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	5.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	6.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	7.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	8.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	9.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	10.	50.00	0.00	0.01	0.00	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	2.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	3.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	4.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	5.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	6.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	7.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	8.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	9.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	10.	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	2.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	3.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	4.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	5.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	6.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	7.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	8.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	9.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INITIAL COND-2	10.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.000	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	2.	0.200	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00

INCR INFLOW-1	3.	0.000	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	4.	0.100	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	5.	0.000	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	6.	0.500	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	7.	0.000	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	8.	0.000	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	9.	0.000	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	10.	1.400	8.50	8.00	3.37	0.00	0.00	0.00	0.00	0.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	2.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	3.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	4.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	5.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	6.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	7.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	8.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	9.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
INCR INFLOW-2	10.	0.00	0.00	0.18	0.00	0.00	0.00	0.00
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT			UPSTRM	JUNCTION	TRIB
STREAM JUNCTION	1.	JNC=	1	13.	16.	15.
STREAM JUNCTION	2.	JNC=	2	17.	20.	19.
STREAM JUNCTION	3.	JNC=	3	22.	25.	24.
STREAM JUNCTION	4.	JNC=	4	26.	29.	28.
ENDATA9	0.			0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	Hw10 HyElID 5	0.50	8.50	8.00	3.37	0.00	0.00	0.00
HEADWTR-1	2.	Hw11 HyElID 11	0.20	8.50	8.00	3.37	0.00	0.00	0.00
HEADWTR-1	3.	Re11 HyElID 70	9.23	8.50	8.29	2.23	0.00	0.00	0.00
HEADWTR-1	4.	Hw12 HyElID 48	1.00	8.50	8.00	3.37	0.00	0.00	0.00
HEADWTR-1	5.	Hw15 HyElID 12	5.34	8.50	4.59	2.30	0.00	0.00	0.00
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS, COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
HEADWTR-2	2.	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
HEADWTR-2	3.	0.00	0.00	0.00	0.00	0.21	0.13	0.12	0.00	0.00
HEADWTR-2	4.	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
HEADWTR-2	5.	0.00	0.00	0.00	0.00	0.28	0.29	0.75	0.00	0.00
ENDATA10A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	St.Al+Cheese	0.00	0.00	8.50	4.00	43.90	0.00	0.00	0.00
POINTLD-1	2.	Casselman	0.00	0.11	8.50	4.00	43.90	0.00	0.00	0.00
ENDATA11	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS, COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	POINT LOAD ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
POINTLD-2	1.	0.00	0.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00
POINTLD-2	2.	0.00	0.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00
ENDATA11A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

	DAM	RCH	ELE	ADAM	BDAM	FDAM	HDAM
ENDATA12	0.	0.	0.	0.00	0.00	0.00	0.00

$$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

CARD TYPE	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
ENDATA13	DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED							

$$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

CARD TYPE	CHL-A	ORG-N	NH3-N	NO2-N	NH3-N	ORG-P	DIS-P
ENDATA13A	DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED						

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STEADY STATE TEMPERATURE SIMULATION; CONVERGENCE SUMMARY:
---------------------------------------------------------

                    NUMBER OF
       ITERATION  NONCONVERGENT
                    ELEMENTS

           1           21
           2            0

SUMMARY OF VALUES FOR STEADY STATE TEMPERATURE CALCULATIONS (SUBROUTINE HEATER):
--------------------------------------------------------------------------------

     DAILY NET SOLAR RADIATION =    2005.635 BTU/FT-2    (  544.270 LANGLEYS)
     NUMBER OF DAYLIGHT HOURS =  13.0


     HOURLY VALUES OF SOLAR RADIATION (BTU/FT-2)

           1     0.00          9   155.90         17   106.46
           2     0.00         10   202.04         18    47.68
           3     0.00         11   235.61         19     2.28
           4     0.00         12   253.61         20     0.00
           5     0.00         13   254.40         21     0.00
           6     0.07         14   237.92         22     0.00
           7    42.24         15   205.66         23     0.00
           8   101.26         16   160.51         24     0.00
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STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 1
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** HYDRAULICS SUMMARY **

ELE ORD	RCH NUM	ELE NUM	BEGIN LOC KILO	END LOC KILO	FLOW CMS	POINT SRCE CMS	INCR FLOW CMS	VEL MPS	TRVL TIME DAY	DEPTH M	WIDTH M	VOLUME K-CU-M	BOTTOM AREA K-SQ-M	X-SECT AREA SQ-M	DSPRSN COEF SQ-M/S
1	1	1	60.00	58.00	0.50	0.00	0.00	0.667	0.035	0.300	2.497	1.50	6.20	0.75	3.07
2	1	2	58.00	56.00	0.50	0.00	0.00	0.667	0.035	0.300	2.497	1.50	6.20	0.75	3.07
3	1	3	56.00	54.00	0.50	0.00	0.00	0.667	0.035	0.300	2.497	1.50	6.20	0.75	3.07
4	1	4	54.00	52.00	0.50	0.00	0.00	0.667	0.035	0.300	2.497	1.50	6.20	0.75	3.07
5	1	5	52.00	50.00	0.50	0.00	0.00	0.667	0.035	0.300	2.497	1.50	6.20	0.75	3.07
6	1	6	50.00	48.00	0.50	0.00	0.00	0.667	0.035	0.300	2.497	1.50	6.20	0.75	3.07
7	2	1	48.00	46.00	0.53	0.00	0.03	0.380	0.061	0.559	2.489	2.78	7.22	1.39	2.93
8	2	2	46.00	44.00	0.56	0.00	0.03	0.388	0.060	0.577	2.489	2.87	7.29	1.44	3.07
9	2	3	44.00	42.00	0.59	0.00	0.03	0.396	0.059	0.595	2.489	2.96	7.36	1.48	3.22
10	2	4	42.00	40.00	0.61	0.00	0.03	0.403	0.057	0.612	2.489	3.05	7.43	1.52	3.36
11	2	5	40.00	38.00	0.64	0.00	0.03	0.411	0.056	0.629	2.489	3.13	7.50	1.57	3.50
12	2	6	38.00	36.00	0.67	0.00	0.03	0.418	0.055	0.646	2.489	3.21	7.56	1.61	3.64
13	2	7	36.00	34.00	0.70	0.00	0.03	0.425	0.054	0.662	2.489	3.30	7.63	1.65	3.78
14	3	1	4.00	2.00	0.20	0.00	0.00	0.268	0.086	0.301	2.482	1.49	6.17	0.75	1.23
15	3	2	2.00	0.00	0.20	0.00	0.00	0.268	0.086	0.301	2.482	1.49	6.17	0.75	1.23
16	4	1	34.00	32.00	0.95	0.00	0.05	0.294	0.079	1.018	3.175	6.47	10.42	3.23	3.74
17	4	2	32.00	30.00	1.00	0.00	0.05	0.300	0.077	1.050	3.175	6.67	10.55	3.33	3.91
18	5	1	4.00	2.00	9.23	0.00	0.00	0.185	0.125	2.656	18.797	99.87	48.23	49.92	5.23
19	5	2	2.00	0.00	9.23	0.00	0.00	0.185	0.125	2.656	18.797	99.87	48.23	49.92	5.23
20	6	1	30.00	28.00	10.40	0.00	0.17	0.209	0.111	2.649	18.762	99.41	48.13	49.70	5.90
21	6	2	28.00	26.00	10.56	0.00	0.17	0.211	0.110	2.674	18.762	100.37	48.23	50.17	5.99
22	6	3	26.00	24.00	10.73	0.00	0.17	0.212	0.109	2.699	18.762	101.32	48.33	50.65	6.07
23	7	1	4.00	2.00	1.00	0.00	0.00	0.076	0.305	2.200	5.981	26.32	20.77	13.16	1.84
24	7	2	2.00	0.00	1.00	0.00	0.00	0.076	0.305	2.200	5.981	26.32	20.77	13.16	1.84

25	8	1	24.00	22.00	11.73	0.00	0.00	0.161	0.144	2.997	24.366	146.07	60.73	73.02	5.02
26	8	2	22.00	20.00	11.73	0.00	0.00	0.161	0.144	2.997	24.366	146.07	60.73	73.02	5.02
27	9	1	4.00	2.00	5.34	0.00	0.00	0.082	0.282	2.869	22.676	130.14	56.84	65.05	2.47
28	9	2	2.00	0.00	5.34	0.00	0.00	0.082	0.282	2.869	22.676	130.14	56.84	65.05	2.47

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 2
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** HYDRAULICS SUMMARY **

ELE ORD	RCH NUM	ELE NUM	BEGIN LOC KILO	END LOC KILO	FLOW CMS	POINT SRCE CMS	INCR FLOW CMS	VEL MPS	TRVL TIME DAY	DEPTH M	WIDTH M	VOLUME K-CU-M	BOTTOM AREA K-SQ-M	X-SECT AREA SQ-M	DSPRSN COEF SQ-M/S
29	10	1	20.00	18.00	17.21	0.00	0.14	0.159	0.145	2.933	36.857	216.29	85.47	108.12	4.89
30	10	2	18.00	16.00	17.35	0.00	0.14	0.160	0.145	2.948	36.857	217.34	85.52	108.65	4.92
31	10	3	16.00	14.00	17.60	0.11	0.14	0.161	0.144	2.973	36.857	219.18	85.62	109.57	4.99
32	10	4	14.00	12.00	17.74	0.00	0.14	0.161	0.144	2.987	36.857	220.23	85.68	110.09	5.02
33	10	5	12.00	10.00	17.88	0.00	0.14	0.162	0.143	3.001	36.857	221.27	85.74	110.61	5.06
34	10	6	10.00	8.00	18.02	0.00	0.14	0.162	0.143	3.015	36.857	222.31	85.79	111.13	5.09
35	10	7	8.00	6.00	18.16	0.00	0.14	0.163	0.142	3.029	36.857	223.34	85.85	111.65	5.13
36	10	8	6.00	4.00	18.30	0.00	0.14	0.163	0.142	3.043	36.857	224.37	85.91	112.16	5.17
37	10	9	4.00	2.00	18.44	0.00	0.14	0.164	0.142	3.057	36.857	225.40	85.96	112.68	5.20
38	10	10	2.00	0.00	18.58	0.00	0.14	0.164	0.141	3.071	36.857	226.43	86.02	113.19	5.24

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 3
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** REACTION COEFFICIENT SUMMARY **

RCH NUM	ELE NUM	DO SAT MG/L	K2 OPT	OXYGN REAIR 1/DAY	BOD DECAY 1/DAY	BOD SETT 1/DAY	SOD RATE G/M2D	ORGN DECAY 1/DAY	ORGN SETT 1/DAY	NH3 DECAY 1/DAY	NH3 SRCE MG/M2D	NO2 DECAY 1/DAY	ORGP DECAY 1/DAY	ORGP SETT 1/DAY	DISP SRCE MG/M2D	COLI DECAY 1/DAY	ANC DECAY 1/DAY	ANC SETT 1/DAY	ANC SRCE MG/M2D
1	1	11.35	3	15.08	0.30	0.00	0.52	0.00	0.00	0.41	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	2	11.24	3	15.23	0.31	0.00	0.54	0.00	0.00	0.43	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	3	11.13	3	15.37	0.31	0.00	0.55	0.00	0.00	0.44	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	4	11.02	3	15.52	0.32	0.00	0.56	0.00	0.00	0.46	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	5	10.92	3	15.67	0.32	0.00	0.58	0.00	0.00	0.47	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	6	10.82	3	15.81	0.33	0.00	0.59	0.00	0.00	0.48	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1	10.76	3	10.31	0.33	0.00	0.60	0.00	0.00	0.49	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2	10.71	3	4.66	0.34	0.00	0.60	0.00	0.00	0.50	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	3	10.67	3	4.51	0.34	0.00	0.61	0.00	0.00	0.51	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4	10.62	3	4.38	0.34	0.00	0.62	0.00	0.00	0.52	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	5	10.59	3	4.25	0.34	0.00	0.62	0.00	0.00	0.52	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	6	10.56	3	4.13	0.35	0.00	0.63	0.00	0.00	0.53	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	7	10.52	3	4.03	0.35	0.00	0.63	0.00	0.00	0.53	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	1	11.19	3	9.66	0.31	0.00	0.54	0.00	0.00	0.43	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	2	10.93	3	9.89	0.32	0.00	0.57	0.00	0.00	0.47	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	1	10.61	3	4.39	0.34	0.00	0.62	0.00	0.00	0.52	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	2	10.59	3	1.69	0.34	0.00	0.62	0.00	0.00	0.52	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1	11.42	3	0.30	0.30	0.00	0.52	0.00	0.00	0.40	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	2	11.37	3	0.30	0.30	0.00	0.52	0.00	0.00	0.41	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	1	11.25	3	0.63	0.31	0.00	0.53	0.00	0.00	0.42	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	2	11.22	3	0.32	0.31	0.00	0.54	0.00	0.00	0.43	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	3	11.18	3	0.32	0.31	0.00	0.54	0.00	0.00	0.43	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1	11.33	3	0.26	0.30	0.00	0.53	0.00	0.00	0.42	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	2	11.20	3	0.26	0.31	0.00	0.54	0.00	0.00	0.43	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00

8	1	11.15	3	0.26	0.31	0.00	0.55	0.00	0.00	0.44	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	2	11.11	3	0.24	0.31	0.00	0.55	0.00	0.00	0.44	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1	11.37	3	0.18	0.30	0.00	0.52	0.00	0.00	0.41	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	2	11.27	3	0.18	0.30	0.00	0.53	0.00	0.00	0.42	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 4
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** REACTION COEFFICIENT SUMMARY **

RCH NUM	ELE NUM	DO SAT MG/L	K2 OPT	OXYGN REAIR 1/DAY	BOD DECAY 1/DAY	BOD SETT 1/DAY	SOD RATE G/M2D	ORGN DECAY 1/DAY	ORGN SETT 1/DAY	NH3 DECAY 1/DAY	NH3 SRCE MG/M2D	NO2 DECAY 1/DAY	ORGP DECAY 1/DAY	ORGP SETT 1/DAY	DISP SRCE MG/M2D	COLI DECAY 1/DAY	ANC DECAY 1/DAY	ANC SETT 1/DAY	ANC SRCE MG/M2D
10	1	11.13	3	0.23	0.31	0.00	0.55	0.00	0.00	0.44	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	2	11.08	3	0.25	0.31	0.00	0.56	0.00	0.00	0.45	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	3	11.04	3	0.25	0.32	0.00	0.56	0.00	0.00	0.45	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	4	11.01	3	0.24	0.32	0.00	0.56	0.00	0.00	0.46	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	5	10.97	3	0.24	0.32	0.00	0.57	0.00	0.00	0.46	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	6	10.93	3	0.24	0.32	0.00	0.57	0.00	0.00	0.47	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	7	10.89	3	0.24	0.33	0.00	0.58	0.00	0.00	0.47	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8	10.86	3	0.24	0.33	0.00	0.58	0.00	0.00	0.48	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	9	10.82	3	0.24	0.33	0.00	0.59	0.00	0.00	0.49	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	10	10.79	3	0.24	0.33	0.00	0.59	0.00	0.00	0.49	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 5
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** WATER QUALITY VARIABLES **

RCH NUM	ELE NUM	TEMP DEG-C	CM-1 Cl mg/L	CM-2 Fe mg/L	CM-3 Br mg/L	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L	COLI #/100ML	ANC	CHLA UG/L
1	1	8.92	0.00	0.00	0.00	9.07	3.34	0.00	0.18	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
1	2	9.33	0.00	0.00	0.00	9.74	3.30	0.00	0.18	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
1	3	9.73	0.00	0.00	0.00	10.14	3.26	0.00	0.17	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
1	4	10.14	0.00	0.00	0.00	10.37	3.23	0.00	0.17	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
1	5	10.53	0.00	0.00	0.00	10.48	3.19	0.00	0.17	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
1	6	10.93	0.00	0.00	0.00	10.52	3.16	0.00	0.17	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	1	11.16	0.00	0.00	0.00	10.40	3.12	0.00	0.16	0.02	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	2	11.37	0.00	0.00	0.00	10.24	3.07	0.00	0.16	0.02	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	3	11.56	0.00	0.00	0.00	10.11	3.03	0.00	0.16	0.02	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	4	11.73	0.00	0.00	0.00	10.00	2.99	0.00	0.15	0.03	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	5	11.88	0.00	0.00	0.00	9.92	2.95	0.00	0.15	0.03	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	6	12.02	0.00	0.00	0.00	9.84	2.91	0.00	0.15	0.03	0.01	0.18	0.00	0.00	0.00	0.00	0.00	0.00
2	7	12.14	0.00	0.00	0.00	9.78	2.87	0.00	0.14	0.03	0.01	0.18	0.00	0.00	0.00	0.00	0.00	0.00
3	1	9.52	0.00	0.00	0.00	9.28	3.28	0.00	0.18	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
3	2	10.50	0.00	0.00	0.00	9.87	3.19	0.00	0.17	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
4	1	11.80	0.00	0.00	0.00	9.74	2.92	0.00	0.15	0.03	0.01	0.18	0.00	0.00	0.00	0.00	0.00	0.00
4	2	11.86	0.00	0.00	0.00	9.60	2.86	0.00	0.14	0.03	0.01	0.18	0.00	0.00	0.00	0.00	0.00	0.00
5	1	8.67	0.00	0.00	0.00	8.25	2.15	0.00	0.20	0.13	0.13	0.46	0.00	0.00	0.00	0.00	0.00	0.00
5	2	8.85	0.00	0.00	0.00	8.22	2.07	0.00	0.19	0.13	0.14	0.46	0.00	0.00	0.00	0.00	0.00	0.00
6	1	9.27	0.00	0.00	0.00	8.39	2.13	0.00	0.18	0.12	0.13	0.43	0.00	0.00	0.00	0.00	0.00	0.00
6	2	9.40	0.00	0.00	0.00	8.35	2.08	0.00	0.17	0.12	0.14	0.42	0.00	0.00	0.00	0.00	0.00	0.00
6	3	9.53	0.00	0.00	0.00	8.31	2.03	0.00	0.16	0.11	0.14	0.42	0.00	0.00	0.00	0.00	0.00	0.00
7	1	9.00	0.00	0.00	0.00	7.79	3.09	0.00	0.16	0.02	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
7	2	9.49	0.00	0.00	0.00	7.60	2.81	0.00	0.14	0.03	0.01	0.19	0.00	0.00	0.00	0.00	0.00	0.00

8	1	9.64	0.00	0.00	0.00	8.21	2.04	0.00	0.16	0.11	0.14	0.40	0.00	0.00	0.00	0.00	0.00	0.00
8	2	9.81	0.00	0.00	0.00	8.13	1.95	0.00	0.15	0.11	0.15	0.40	0.00	0.00	0.00	0.00	0.00	0.00
9	1	8.85	0.00	0.00	0.00	4.54	2.12	0.00	0.25	0.27	0.80	1.32	0.00	0.00	0.00	0.00	0.00	0.00
9	2	9.21	0.00	0.00	0.00	4.55	1.95	0.00	0.22	0.25	0.83	1.31	0.00	0.00	0.00	0.00	0.00	0.00

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 6
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** WATER QUALITY VARIABLES **

RCH NUM	ELE NUM	TEMP DEG-C	CM-1 Cl mg/L	CM-2 Fe mg/L	CM-3 Br mg/L	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L	COLI #/100ML	ANC	CHLA UG/L
10	1	9.74	0.00	0.00	0.00	6.99	1.90	0.00	0.16	0.15	0.37	0.68	0.00	0.00	0.00	0.00	0.00	0.00
10	2	9.90	0.00	0.00	0.00	6.98	1.83	0.00	0.15	0.15	0.38	0.68	0.00	0.00	0.00	0.00	0.00	0.00
10	3	10.05	0.00	0.00	0.00	6.93	2.00	0.00	0.22	0.15	0.39	0.76	0.00	0.00	0.00	0.00	0.00	0.00
10	4	10.21	0.00	0.00	0.00	6.90	1.93	0.00	0.21	0.14	0.40	0.75	0.00	0.00	0.00	0.00	0.00	0.00
10	5	10.36	0.00	0.00	0.00	6.87	1.85	0.00	0.20	0.14	0.41	0.75	0.00	0.00	0.00	0.00	0.00	0.00
10	6	10.51	0.00	0.00	0.00	6.85	1.78	0.00	0.18	0.14	0.42	0.74	0.00	0.00	0.00	0.00	0.00	0.00
10	7	10.65	0.00	0.00	0.00	6.84	1.71	0.00	0.17	0.14	0.43	0.74	0.00	0.00	0.00	0.00	0.00	0.00
10	8	10.79	0.00	0.00	0.00	6.83	1.65	0.00	0.16	0.14	0.44	0.73	0.00	0.00	0.00	0.00	0.00	0.00
10	9	10.93	0.00	0.00	0.00	6.82	1.59	0.00	0.15	0.13	0.45	0.73	0.00	0.00	0.00	0.00	0.00	0.00
10	10	11.07	0.00	0.00	0.00	6.81	1.53	0.00	0.14	0.13	0.45	0.73	0.00	0.00	0.00	0.00	0.00	0.00

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 7
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** DISSOLVED OXYGEN DATA **

ELE ORD	RCH NUM	ELE NUM	TEMP DEG-C	DO SAT MG/L	DO MG/L	DO DEF MG/L	DAM INPUT MG/L	NIT INHIB FACT	F-FNCTN INPUT	OXYGN REAIR	C-BOD	SOD	NET P-R	NH3-N	NO2-N
									COMPONENTS OF DISSOLVED OXYGEN MASS BALANCE (MG/L-DAY)						
1	1	1	8.92	11.35	9.07	2.28	0.00	1.00	230.43	34.33	-1.00	-1.75	0.00	-0.26	0.00
2	1	2	9.33	11.24	9.74	1.50	0.00	1.00	0.00	22.78	-1.01	-1.79	0.00	-0.26	0.00
3	1	3	9.73	11.13	10.14	0.99	0.00	1.00	0.00	15.16	-1.02	-1.83	0.00	-0.27	0.00
4	1	4	10.14	11.02	10.37	0.65	0.00	1.00	0.00	10.16	-1.03	-1.87	0.00	-0.27	-0.01
5	1	5	10.53	10.92	10.48	0.44	0.00	1.00	0.00	6.91	-1.03	-1.92	0.00	-0.28	-0.01
6	1	6	10.93	10.82	10.52	0.31	0.00	1.00	0.00	4.83	-1.04	-1.96	0.00	-0.28	-0.01
7	2	1	11.16	10.76	10.40	0.36	0.00	1.00	7.09	3.75	-1.04	-1.07	0.00	-0.28	-0.01
8	2	2	11.37	10.71	10.24	0.47	0.00	1.00	6.87	2.21	-1.03	-1.05	0.00	-0.28	-0.01
9	2	3	11.56	10.67	10.11	0.56	0.00	1.00	6.67	2.52	-1.03	-1.03	0.00	-0.28	-0.02
10	2	4	11.73	10.62	10.00	0.62	0.00	1.00	6.48	2.72	-1.02	-1.01	0.00	-0.28	-0.02
11	2	5	11.88	10.59	9.92	0.67	0.00	1.00	6.31	2.85	-1.01	-0.99	0.00	-0.27	-0.02
12	2	6	12.02	10.56	9.84	0.71	0.00	1.00	6.14	2.95	-1.01	-0.97	0.00	-0.27	-0.02
13	2	7	12.14	10.52	9.78	0.75	0.00	1.00	5.99	3.00	-1.00	-0.96	0.00	-0.27	-0.02
14	3	1	9.52	11.19	9.28	1.90	0.00	1.00	92.57	18.40	-1.01	-1.80	0.00	-0.27	0.00
15	3	2	10.50	10.93	9.87	1.06	0.00	1.00	0.00	10.51	-1.03	-1.91	0.00	-0.28	-0.01
16	4	1	11.80	10.61	9.74	0.86	0.00	1.00	5.34	3.80	-1.00	-0.61	0.00	-0.27	-0.02
17	4	2	11.86	10.59	9.60	0.99	0.00	1.00	5.18	1.67	-0.99	-0.59	0.00	-0.26	-0.02
18	5	1	8.67	11.42	8.25	3.16	0.00	1.00	66.20	0.95	-0.64	-0.19	0.00	-0.28	-0.08
19	5	2	8.85	11.37	8.22	3.15	0.00	1.00	0.00	0.95	-0.62	-0.20	0.00	-0.27	-0.08
20	6	1	9.27	11.25	8.39	2.86	0.00	1.00	1.16	1.80	-0.65	-0.20	0.00	-0.27	-0.07
21	6	2	9.40	11.22	8.35	2.87	0.00	1.00	1.15	0.93	-0.64	-0.20	0.00	-0.26	-0.07
22	6	3	9.53	11.18	8.31	2.87	0.00	1.00	1.14	0.92	-0.63	-0.20	0.00	-0.25	-0.07
23	7	1	9.00	11.33	7.79	3.53	0.00	1.00	26.26	0.91	-0.93	-0.24	0.00	-0.24	-0.01

24	7	2	9.49	11.20	7.60	3.59	0.00	1.00	0.00	0.93	-0.87	-0.25	0.00	-0.22	-0.02
25	8	1	9.64	11.15	8.21	2.95	0.00	1.00	0.00	0.78	-0.63	-0.18	0.00	-0.24	-0.07
26	8	2	9.81	11.11	8.13	2.98	0.00	1.00	0.00	0.71	-0.61	-0.18	0.00	-0.23	-0.07
27	9	1	8.85	11.37	4.54	6.82	0.00	1.00	16.27	1.22	-0.64	-0.18	0.00	-0.36	-0.16
28	9	2	9.21	11.27	4.55	6.72	0.00	1.00	0.00	1.21	-0.60	-0.19	0.00	-0.33	-0.16

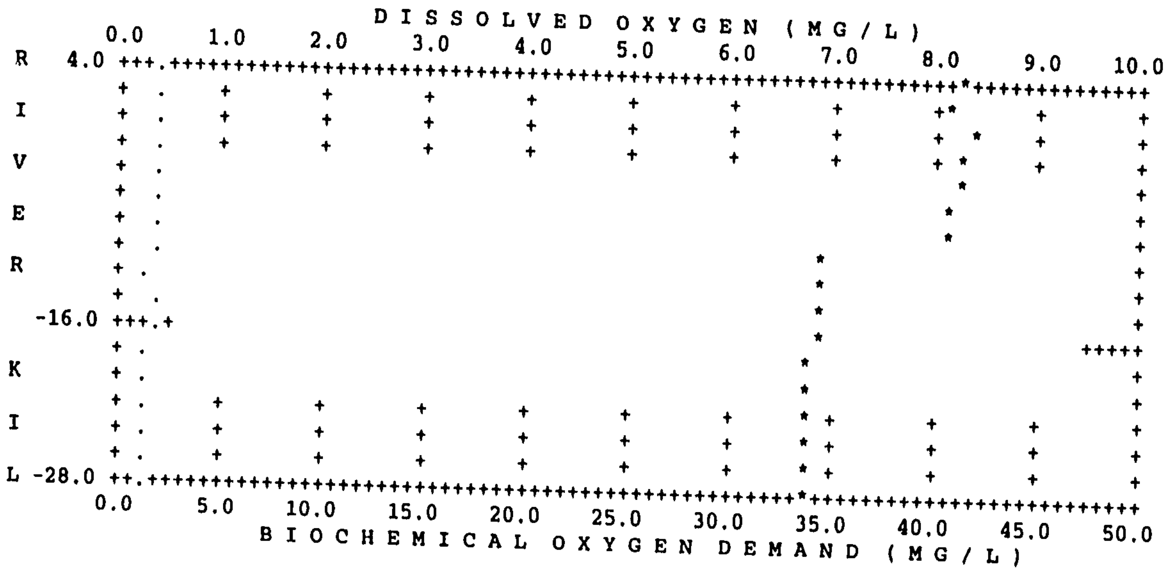
STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 8
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

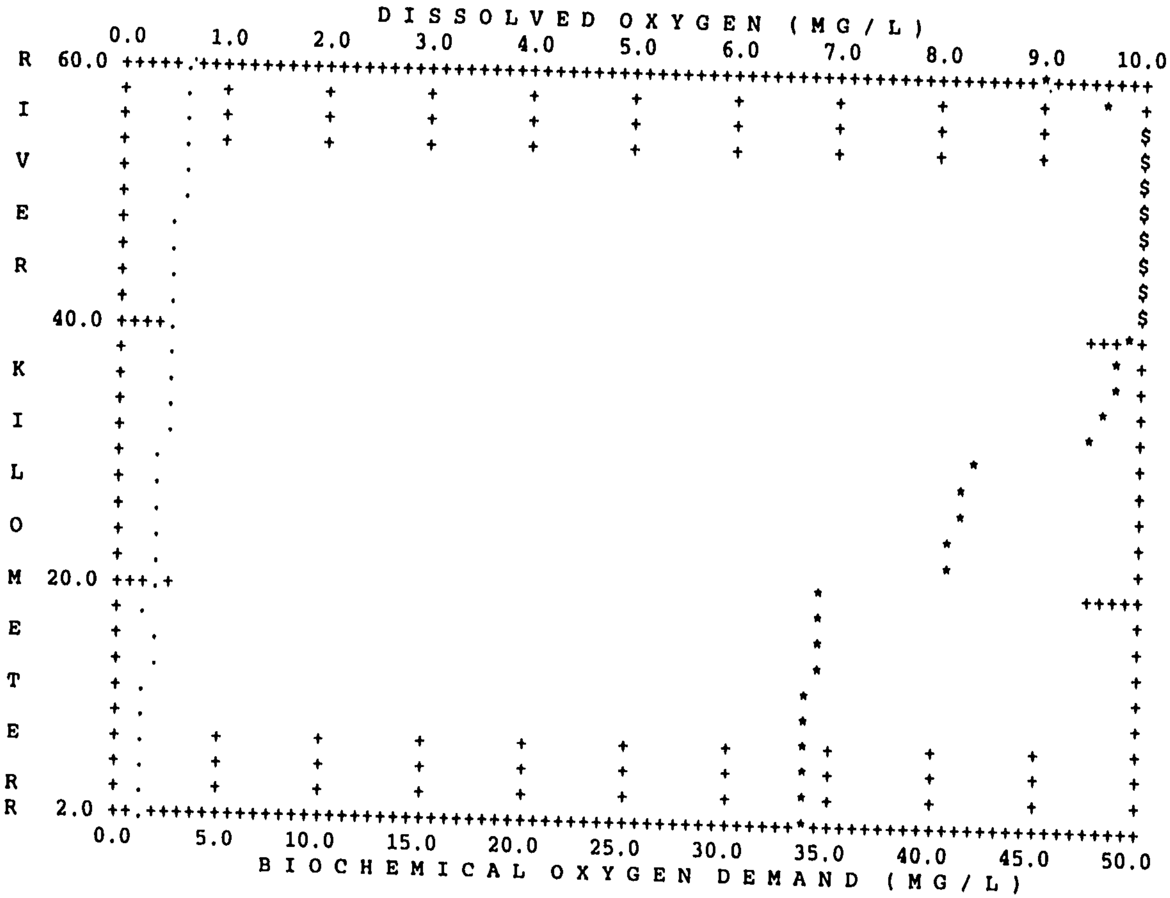
** DISSOLVED OXYGEN DATA **

ELE ORD	RCH NUM	ELE NUM	TEMP DEG-C	DO SAT MG/L	DO MG/L	DO DEF MG/L	DAM INPUT MG/L	NIT INHIB FACT	COMPONENTS OF DISSOLVED OXYGEN MASS BALANCE (MG/L-DAY) F-FNCTN INPUT	OXYGN REAIR	C-BOD	SOD	NET P-R	NH3-N	NO2-N
29	10	1	9.74	11.13	6.99	4.14	0.00	1.00	0.45	0.95	-0.59	-0.19	0.00	-0.25	-0.09
30	10	2	9.90	11.08	6.98	4.11	0.00	1.00	0.45	1.01	-0.58	-0.19	0.00	-0.24	-0.09
31	10	3	10.05	11.04	6.93	4.12	0.00	1.00	0.61	1.01	-0.63	-0.19	0.00	-0.35	-0.09
32	10	4	10.21	11.01	6.90	4.11	0.00	1.00	0.44	1.00	-0.61	-0.19	0.00	-0.33	-0.09
33	10	5	10.36	10.97	6.87	4.09	0.00	1.00	0.44	1.00	-0.59	-0.19	0.00	-0.32	-0.09
34	10	6	10.51	10.93	6.85	4.07	0.00	1.00	0.44	0.99	-0.58	-0.19	0.00	-0.30	-0.09
35	10	7	10.65	10.89	6.84	4.05	0.00	1.00	0.43	0.98	-0.56	-0.19	0.00	-0.28	-0.09
36	10	8	10.79	10.86	6.83	4.03	0.00	1.00	0.43	0.98	-0.54	-0.19	0.00	-0.27	-0.09
37	10	9	10.93	10.82	6.82	4.00	0.00	1.00	0.43	0.97	-0.52	-0.19	0.00	-0.26	-0.09
38	10	10	11.07	10.79	6.81	3.98	0.00	1.00	0.43	0.96	-0.51	-0.19	0.00	-0.24	-0.09



DISSOLVED OXYGEN = * * * *

BIOCHEMICAL OXYGEN DEMAND = ...



DISSOLVED OXYGEN = * * * *

BIOCHEMICAL OXYGEN DEMAND = ...