WQ2000: WATER QUALITY MODELLING ASSESSMENT SYSTEM

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ABSTRACT

WQ2000 is an interactive system for rapidly assessing quaternary catchment salinity for naturalised and developed conditions. This Water Research Commission product can also provide a regional overview of salinity conditions. It is designed to complement the WR90 water resources manual (soon to be updated to WR2005) and incorporates powerful and flexible "What if?" capabilities for assessing proposed new developments.

A simple to use but versatile interface links the user to an extensive database and facilitates interaction with the sophisticated WQT monthly time step hydro-salinity model. The database contains seventy-year monthly time series of rainfall, naturalised pervious and urban catchment runoff, calibrated WQT model hydro-salinity parameter values and a wide range of natural and present day development characteristics. The initial implementation is for the 192 quaternary catchments of the Vaal River, ranging from undeveloped areas to some of the most developed catchments in South Africa.

After selection of a quaternary catchment, the WQT hydro-salinity model is run for seventy years of monthly hydrology for natural and present day developed conditions for off-channel conditions and taking account of the cumulative inflow from upstream catchments. These four simulations are run seamlessly and invisibly without the user needing any expertise in using the complex WQT model. Provision is made to change any of the default values to reflect the impact of expected or planned developments. WQ2000 places a powerful and rapid assessment tool in the hands of a wide range of practitioners.

The model basis, its structure and uses, limitations and potential enhancements are discussed.

INTRODUCTION

WQ2000 is a product of a RSA Water Research Commission project (1). It is an interactive computer program for rapidly assessing quaternary catchment salinity for naturalised and developed conditions. It can also be used to provide a regional overview of salinity conditions. WQ2000 is designed to complement the WR90 (2) water resources manual (soon to be updated to WR2005) and incorporates powerful and flexible "What if?" capabilities for assessing the impact of proposed new developments.

What is in It?

WQ2000 incorporates a simple to use but versatile interface that links the user to an extensive database, the sophisticated WQT monthly time step hydro-salinity model and the Department of Water Affairs' (DWAF) GIS Viewer (3). The WQ2000 model layout is shown in Figure 1.

The database contains seventy-year monthly time series of rainfall, naturalised pervious and urban catchment runoff and calibrated WQT hydro-salinity model (4) parameter values. The intrinsic characteristics of each quaternary catchment are stored, including catchment area, mean annual precipitation, mean monthly evaporation, mean annual runoff, Symons Pan to catchment and lake evaporation factors and its linkage to adjacent quaternary catchments.

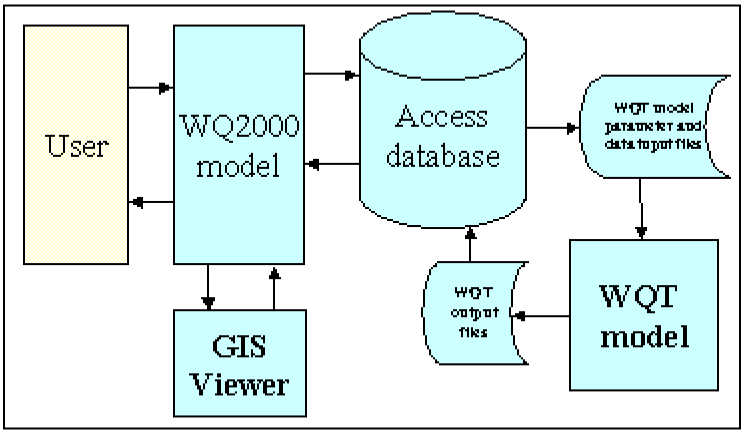

Figure 1. WQ2000 model structure.

The database includes extensive default information on present day development, including urbanisation, irrigation, wetlands, bed loss, major and minor dams, mine and effluent discharge, water importation and abstractions. Altogether the database contains over 1300 fields of information to describe each quaternary catchment.

The initial implementation is for the 192 quaternary catchments of the Vaal River covering three Water Management Areas. The WQT model was calibrated for this area during the DWAF Vaal River Water Quality Update study (5,6,7,8). These range from undeveloped areas to some of the most developed catchments in South Africa. The intention is to extend this coverage to the remainder of the country.

What Can I Use it For?

WQ2000 facilitates rapid initial assessment of the impact of proposed development options including:

- Introduction of new dams or changes to existing ones
- Alteration or introduction of new mine or effluent inputs
- Alteration of quantity or quality of the water imported to the catchment
- Change to water abstraction or minimum release from dams
- Growth in urban area or the density of the paved portion of urban area
- Change in irrigated areas supported and unsupported by farm dams or with their supply regulated by the main stem river system as well as the proportions of catchment runoff entering upstream of each category
- Change in wetland area or channel bed loss

An overview showing the state of the quaternaries within a defined catchment can also be generated using the DWAF's GIS Viewer.

What Does it Do?

Once the user has selected a quaternary catchment and made changes to the default development data to reflect the option to be examined, a button can be selected to simulate it. The WQT hydro-salinity model is then run seventy years of monthly hydrology for four conditions.

The four scenarios include:

- Natural conditions for the quaternary itself (off-channel with no influence from upstream catchments)
- Natural conditions with dilution (or pollution) from upstream catchment inflow
- Present day development state for the quaternary catchment alone
- Present day development state with cumulative inflow from upstream catchments

Menu options are provided to display the results or to depict a catchment overview.

Surely the Operator Needs Specialised Modelling Skills?

A particular strength of WQ2000 is that the implementation of development changes and execution of model runs can be carried out rapidly by water resources and water quality management personnel who do not need in-depth knowledge of the underlying sophisticated WQT model. (Such skills are required only for the initial model calibrations and population of the database, which has already been done for the Vaal River catchment.) However, the user does need to be conversant with water resources systems and be able to interpret the flow and water quality results.

But it Costs an Arm and a Leg, Right?

Wrong. WQ2000 was developed by the WRC. As such it will become freely available to practitioners once a DWAF user support system has been set up for it.

USING WQ2000

The procedure followed to use WQT is outlined below.

Project Database

The user may not edit the default database of catchment characteristics and present day (as at September 1995) information. Instead this information is copied into one or more user-defined project databases which can be progressively modified to reflect known changes since September 1995 or the specific development option that is to be simulated. Creation of a new project database or selection of an existing one is quickly and easily done using the start menus.

Selection of Quaternary Catchment

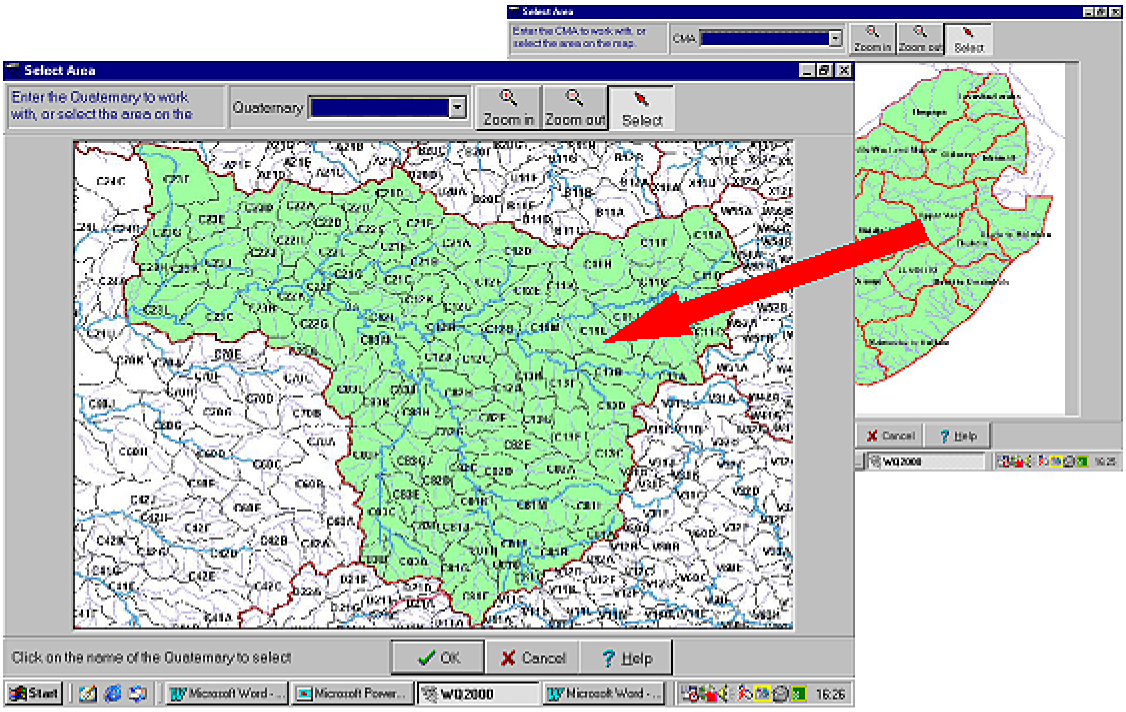

Figure 2. Selection of quaternary catchment from map.

The user is next prompted to select a quaternary catchment. This can be done by direct entry of the quaternary code (e.g. C11C) or by selection from maps of water management areas (Figure 2).

Provision is also made to display the linkage of sub-catchments upstream of the selected quaternary catchment.

Editing Default Data

Having selected a quaternary catchment the user can elect to edit one or more of the default data values. The menu provides three tabs for this purpose. Figure 3 shows changes made via the "Physical data 1" tab.

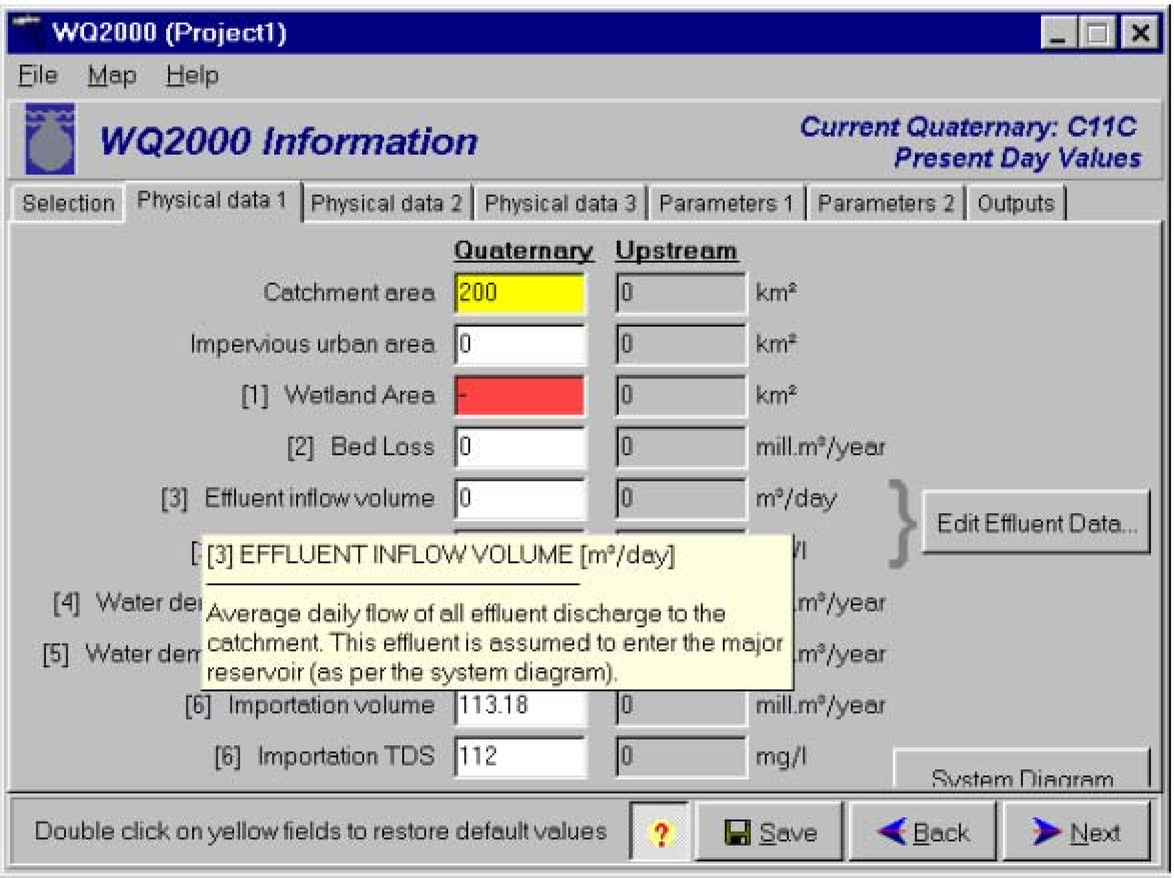

Figure 3. Data changes via tab "Physical Data.

Figure 3 shows the field "Catchment area" highlighted in yellow. This indicates that the area of "200" km^2 has been changed from the previous default value. Double clicking on this field would restore the default value, while selecting the "Save" button would set the new default area to 200 km^2. The "Wetland area" is highlighted in red, indicating that an invalid (in this case non-numeric) or out of range value has been specified. Resting the cursor on a field or its description produces a pop-up note giving further description of the item (in this case for the effluent inflow volume). A user manual can also be accessed via the help menu.

The field descriptions in Figure 3 are preceded by numbers enclosed in square brackets. These refer to numbered points in the system diagram (Figure 4), which can be accessed by pressing the "System Diagram" button at the bottom left of the window.

System Diagram

Figure 4 shows the standard system network used by WQ2000 to represent the selected quaternary catchment. It is a simplification of the system network used by the WQT model.

The bottom half of Figure 4 represents the quaternary itself, while the top half represents the cumulative upstream catchment feeding into it. The quaternary catchment network comprises one catchment washoff module [node 13], with a proportion [P1] of its runoff allocated to an aggregated minor dam [node 9] that regulates supply to part of the irrigation area [node 10] and part of the runoff [P2] is available to opportunistic irrigation areas [node 11]. The remainder of the catchment runoff bypasses both the minor dam and unregulated irrigation. The minor dam is an aggregation of small farm and municipal dams located off the main river channel. A point source abstraction [route 5] can be specified for this dam. The flow from these nodes is brought together into a channel reach [node 1], which also receives mine pumpage [route 7] and is subject to bed loss [2]. The channel reach node simulates wetland evapotranspiration processes. A portion [P3] of the outflow from the channel reach is discharged below a major dam [node 8], the rest entering above this dam. The major dam receives effluent discharge [3], inflow from the upstream system [16], stored upstream catchment inflow [15] and water importation [6]. Water demand [4] is abstracted from the major dam, which also has a specified minimum release. Irrigation module [node 12] is supported from the upstream main river system, which is regulated by the major dams. Route [14] is the final outflow at the lower end of the quaternary catchment.

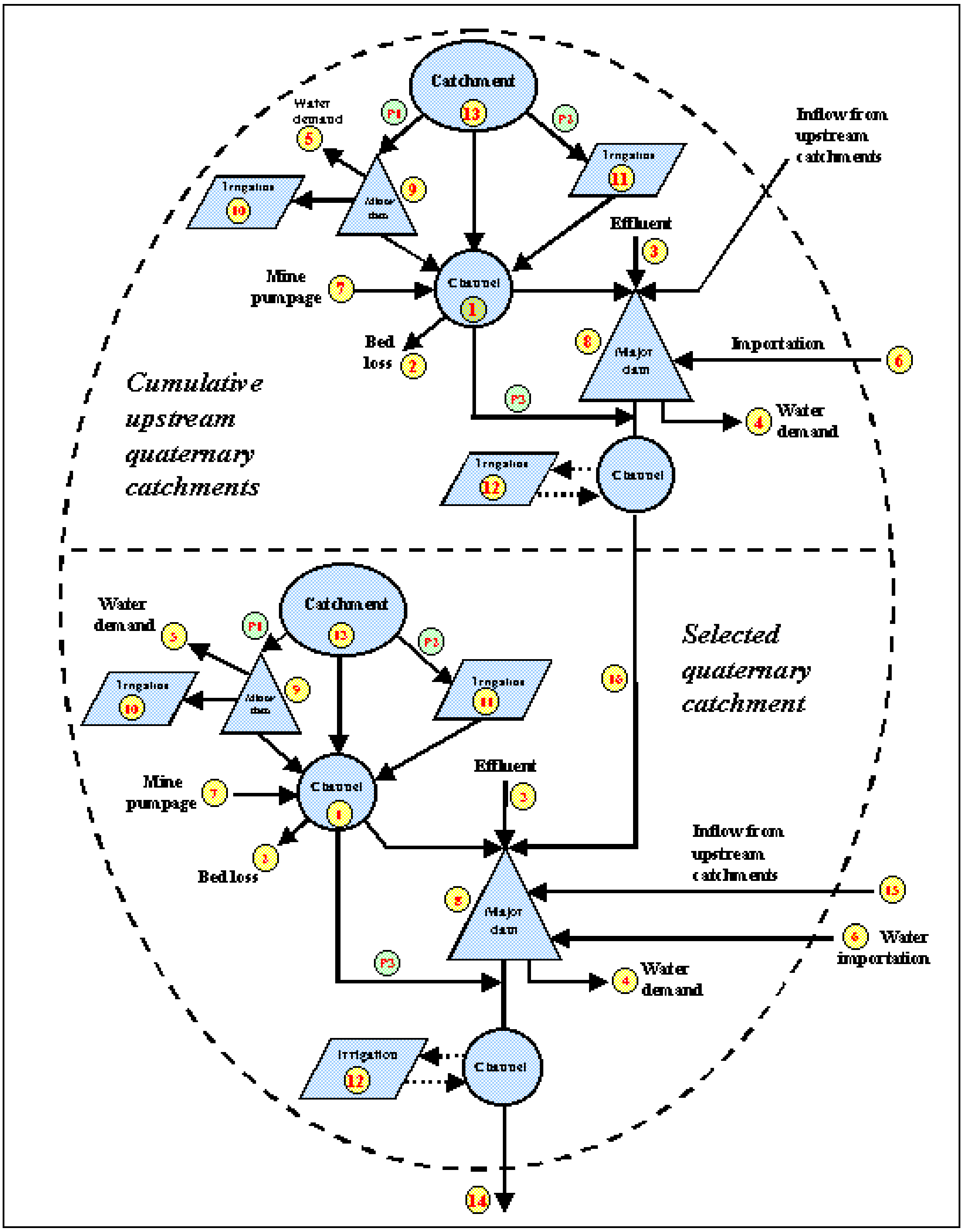

Figure 4. Standard simplified system diagram.

The network for the upstream river system (i.e. the top half of Figure 3) is similar to that for the quaternary catchment. However, in this case the nodes and their associated hydrological time series files are flow- or area-weighted aggregates for the upstream quaternary catchments. Files of simulated monthly outflow and salinity via route [14] can be stored. The stored output then becomes part of the defined input [route 15] for the immediate downstream quaternary catchment. Further down the system, when the selected catchment is separated from the defined flow by one or more quaternary catchments, the defined flows become part of the inflow to the upper sub-system.

Model Simulation

After selection of a quaternary catchment and any desired editing of default development values, the WQT hydro-salinity model is run for seventy years of monthly hydrology for natural and present day developed conditions for both off-channel conditions and taking account of the cumulative inflow from upstream catchments. These four simulations are run seamlessly and invisibly without the user needing any expertise in using the complex WQT model.

Reporting

After simulation of the quaternary catchment a result summary report can be generated. This contains all the run definition data (to identify the summary sheet) and the simulation results for natural and present day conditions with and without the effect of inflows from upstream catchments.

The following results are reported:

- Average outflow Total Dissolved Salts (TDS) concentration (via route 14)
- Median outflow TDS concentration (via route 14)
- 95 percentile outflow TDS concentration (via route 14)
- 98 percentile outflow TDS concentration (via route 14)
- Flow-weighted average outflow TDS concentration (via route 14)
- Average catchment runoff volume (runoff from node 13 before alteration by channel and reservoir storage, irrigation, point inflow or abstraction)
- Average catchment runoff TDS concentration (runoff from node 13)
- Average TDS concentration in major dam (node 8)
- Flow-weighted average TDS concentration of spillage from major Dam (node 8)
- Mean annual outflow volume from quaternary catchment (via route 14)

Regional Overview

The DWAF GIS Viewer facilitates a catchment wide overview by shading each quaternary catchment in a chosen area according to the magnitude of the selected variable. Figure 5 is an example showing the present day distribution of average TDS concentration in the catchment above Grootdraai Dam.

In the example each quaternary catchment has been shaded to reflect the average simulated TDS concentration of the cumulative runoff at its outlet. A plot could also have been generated for incremental catchment conditions, excluding the effect of inflows from upstream quaternary catchments. Two variables have also been included in the pie diagram shown in each quaternary catchment. The variables selected in this case are the average and 95 percentile TDS concentrations simulated at the catchment outlet. Up to three variables can be included in the pie charts.

Various WQT model parameter values (such as the calibrated catchment salt generation rate and the salt washoff efficiency factor) could also have been selected for the area plot and pie charts.

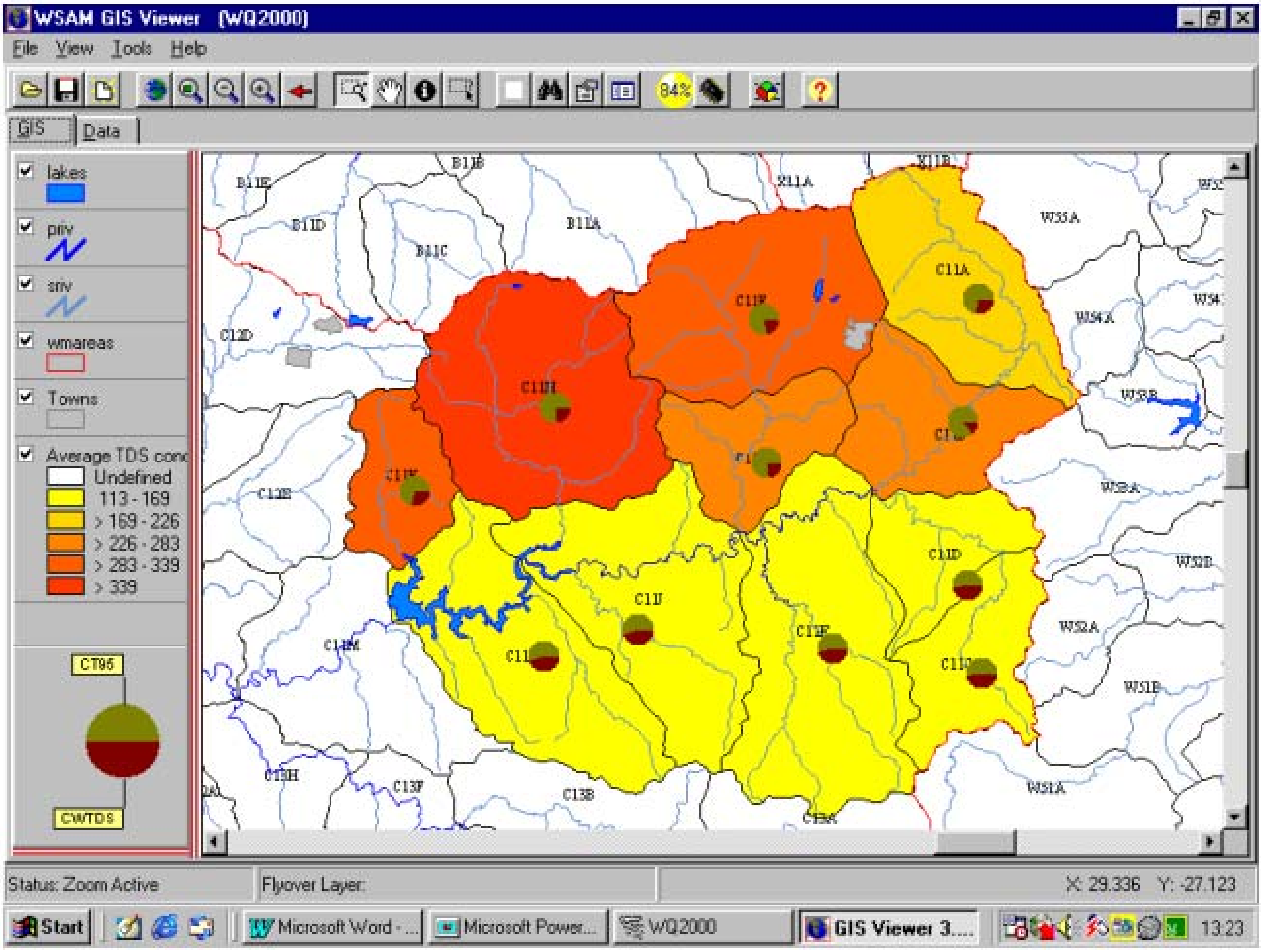

Figure 5. GIS Viewer area plot of average TDS concentration.

Project Databases

The user can save changes in one or more project databases, which can be progressively modified to reflect known developments that have occurred since the default development data was last distributed.

WQT MODEL

The WQT model is the invisible engine at the heart of WQ2000. This is a modular monthly time step hydro-salinity model. A system network is defined linking model nodes (sub-modules) by means of flow routes. The order in which upstream reservoirs are called on to meet downstream water demands is controlled by penalties assigned to each flow route and reservoir storage zone. A simplified version of the system network used in WQ2000 is given in Figure 4.

The following six types of model node are included in WQT:

Salt Washoff Module

The catchment salt washoff module simulates the gradual accumulation of soluble solids within a catchment, their storage and subsequent release during runoff events. Account is taken of both pervious and paved urban catchment surfaces. For pervious surfaces the model simulates the movement of salt via direct surface runoff, infiltration, interflow, sub-surface storage and groundwater flow. Provision is made for the growth of paved urban surfaces and diffuse source salt recharge.

Channel Reach Module

The channel reach sub-model simulates the movement of water and salt through a river reach. The upstream end of the river reach may accept input from up to five source routes. It can also accept a portion of the catchment runoff and salt washoff from an associated catchment salt washoff module. Files of monthly discharges and salt concentrations from mine de-watering may also be specified. Account is taken of riverbed loss and evapotranspiration loss from wetlands. Allowance is made for growth in wetland area, with linear or exponential growth interpolation between years for which areas are specified. The accumulation of salt in wetlands during periods when the potential net evaporation loss exceeds the upstream inflow is also accounted for, with the release of such salts during subsequent flood events. Each channel reach has one downstream outflow route.

An irrigation module may also be associated with the channel reach, to represent riparian irrigation. The irrigation demand is abstracted from the channel and the return seepage discharged to the channel sub-model outflow route.

Irrigation Module

The irrigation sub-model simulates the accumulation of salt within irrigated lands and its release via return seepage. The irrigated land is modelled as a two layered system. Allowance is made for additional flushing during wet periods.

The following processes are simulated:

- Canal transmission losses
- Annual maximum permissible water allocation and its growth or reduction
- Multiple crops (up to 20 may be specified)
- Additional return flow during wet periods
- Losses to relatively inaccessible deep-seated ground water.
- Addition of salts via agricultural lime, gypsum or fertiliser
- Growth or reduction of irrigated area with time
- Variable effective rainfall reduction factors (as function of rainfall intensity)
- Return seepage from two sub-surface zones and via surface spillage from canal ends

The irrigation module is associated with a catchment salt washoff module. As the irrigated area increases, land (and the salt it contains) is transferred to the irrigation model. As irrigated land is take out of service, the land (and its associated salt) is transferred back to the catchment salt washoff model. Linear or exponential interpolation can be used to calculate irrigation areas for years between those for which areas are specified. When the water supply is curtailed the assumption is that the area of land under irrigation is reduced, with part of the land lying fallow. Normal catchment soil evapotranspiration is assumed to apply to fallow areas, until such time as the water availability allows irrigation of the full area to resume. The salt balance is maintained.

The irrigation model can be defined as dependent on a channel reach, or as an independent node with its own water supply and return seepage routes.

Reservoir Module

The reservoir sub-model simulates the monthly water and salt balance of a dam. Account is taken of evaporation loss, rainfall, abstraction and release and spillage driven by inflows to the reservoir. Complete mixing within the reservoir is assumed. This is a reasonable assumption for most reservoirs and the relatively long monthly computational time step.

The water and salt balance equations have been set up in such a manner that a reservoir can be included as part of a dependent salt feedback loop. This facilitates the recycling of salt when water abstracted from the dependent reservoir is supplied to a demand centre, which in turn returns salt-enriched effluent to tributaries draining back into the reservoir. This feature is not used in WQ2000

Junction Node

The junction module simply mixes together the inflows from up to five upstream routes and distributes the outflow to up to five downstream routes. A later enhancement allows for blending, whereby the inflow through preferential routes is adjusted to prevent the outflow TDS concentration from exceeding a defined blending target. Constraints on the capacity of flow routes can also be set. This feature is not required in WQ2000.

Demand Centre Module

The demand centre sub-model simulates the supply of water to meet specified monthly gross water demands and the return of effluent, enriched with salt added during use. The effect of monthly climatic variation on the percentage return flow is simulated. Provision is made for the direct recycling of effluent, with or without desalination. The demand centre may form part of a larger dependent feedback cycle that spans a number of system elements including one dependent reservoir. Each demand centre may accept inputs from up to five source routes, each of which may be independent, or part of the dependent feedback cycle. The simulated monthly effluent discharge and salt load is apportioned to up to five return flow routes.

The standard WQ2000 model system layout does not include any demand centre nodes.

CATCHMENT AGGREGATION

When a quaternary catchment is selected WQ2000 aggregates all upstream quaternary catchment nodes and hydrological files until a defined output is encountered. More than one such defined inflow can occur in a branched river system. When this occurs the defined flow and salinity files are also aggregated. The distribution disk containing the default database comes with defined flow files spaced regularly throughout the Vaal River system. This has been done to speed up the aggregation process after selection of a new quaternary catchment.

All 192 quaternary catchments of the Vaal catchment have also been simulated for the original default conditions and the key results stored in the base dataset. This has been done to permit the generation of regional overview maps using the GIS Viewer without having to first simulate every quaternary catchment. However, after changes to a quaternary catchment have been saved, all downstream quaternary catchments are flagged as no longer having been simulated. This is because cumulative inflow to such quaternaries will then be altered. Any defined downstream flows are also flagged. Thereafter, if a downstream quaternary catchment is selected for simulation, the model will first re-simulate the relevant affected quaternary catchments to re-generate all defined time series files. Similarly, before producing a regional overview map using the GIS Viewer, WQ2000 will automatically re-simulate all flagged quaternary catchments in the specified area to be mapped.

PRACTICAL APPLICATION

WQ2000 has already been used in a study to assess the expected salinity regime in a proposed 168 x $10^6 m^3$ capacity dam in the Klip River catchment to augment the water supply to Sasol 2/3 and Eskom power stations supplied from Grootdraai Dam. Initial examination of the water quality data available at a river monitoring station near the proposed dam site revealed unexpectedly high salinity, with an average TDS concentration of 172 mg/l and a 95-percentile concentration of 282 mg/l. Rapid application of WQ2000 showed that the net effect of dilution by floodwater stored in the dam and evaporative concentration would reduce the average TDS concentration to 130 mg/l and the 95-percentile peak to 148 mg/l. Without the availability of WQ2000 considerable time and effort would have had to be invested to obtain this result.

Further investigation followed to determine the 2030 projected effect of atmospheric deposition, since a distinct upward trend in sulphate concentration was evident in the historical database. The effect on the transferred water from the new dam to Grootdraai Dam was also investigated (9). Although WQ2000 was not used to model this more complex system, the relevant WQT model parameter files were taken from the WQ2000 database. Hence, even for this more detailed investigation for which WQ2000 was not used directly to simulate options, significant savings were realised by making use of the features of WQ2000.

DISCUSSION AND CONCLUSIONS

WQ2000 facilitates changes to any of the default values to reflect anticipated catchment development or to test the impact of planned developments, such as a new dam or changed effluent discharge. This places a powerful, rapid and cost effective assessment tool in the hands of a wide range of practitioners.

Model Use

It is envisaged that licensing authorities and planners would use WQ2000 to make an initial rapid assessment of the effect on salinity of expected or planned development. This would provide a first level sifting of options. At this stage some of the most promising options could be selected prior to more detailed analyses. Further examination of salinity would not be required in those cases where salinity impacts are shown to be negligible or acceptable. Options showing more significant impact would be identified as requiring more detailed examination.

The limited resources available to supply water and sanitation to smaller communities are usually not sufficient to cover the cost of detailed water quality studies. Up to now there has not been a low cost alternative. As a result scant attention has been paid to such impacts. WQ2000 makes it feasible to assess the salinity impacts of even the smallest development schemes. As such WQ2000 is a valuable companion of the WR90 water resources manuals and the WR2005 electronic system that is about to be developed.

The extensive quaternary scale database provides WQT model calibration parameters and data files and catchment development data. Provision is made to access all of the WQT model data files. Thus when more detailed modelling is required an experienced modeller has ready access to prepared and calibrated WQT model data files for the area of interest. These files can then be modified to reflect the more detailed system layout. This again offers substantial saving.

Model Limitations

Currently WQ2000 is limited by the following factors:

- The graphical display options are limited
- There is not yet a trained user base.
- It has been set up only for the Vaal River catchment.
- It handles only TDS
- It is not suitable for large systems spanning more than two major dams

Model Enhancement and Extension

The following enhancements are envisaged:

Model Enhancements and Training

A WRC project has commenced to add options for the graphical display of results. This phase will include other minor enhancements and model testing. It will also involve a pilot training course and address the establishment of a user support system.

Extension of Coverage

The next envisaged step is to extend the coverage to the rest of the country. This should start with those areas where salinity modelling has already formed part of DWAF system analyses. This is logical because the WQT model has already been calibrated for such systems. Moreover, these represent the areas where salinity is of concern. A much coarser coverage will be appropriate for the remaining portion of the country.

Other Water Quality Variables

At present the DWAF system analyses include only salinity modelling (i.e. TDS and one instance where sulphate modelling is used). This is because TDS is the most economically important water quality problem associated with development and the prevalent aridity of South Africa. Conservative pollutants are also the most amenable to reliable modelling. While other pollutants cannot be ignored, it would not be appropriate to model them in WQ2000 to the same degree as for TDS. Another WRC project has commenced to develop WR2005, the successor to the WR90 hydrological database. An overview of water quality will be included in the WR2005 database. This will be much more simplified than the approach used in WQ2000, but it will address a wider range of water quality variables. This could form the kernel for extending the coverage of WQ2000 to other water quality variables.

Large System Modelling
There is no intention to enhance the model to address the last bulleted limitation. WQ2000 was never intended to replace existing detailed system models that have been set up for systems spanning several major inter-connected dams.

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