CASE STUDY FOR LINKING WATER QUALITY LICENSE CONDITIONS WITH RESOURCE QUALITY OBJECTIVES FOR THE LEEU-TAAIBOSCHSPRUIT INDUSTRIAL COMPLEX SITUATED WITHIN THE VAAL BARRAGE CATCHMENT: VOLUME 2

Andrew Slaughter, Neil Griffin and Nelson Odume

WATER RESEARCH COMMISSION

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CASE STUDY FOR LINKING WATER QUALITY LICENSE CONDITIONS WITH RESOURCE QUALITY OBJECTIVES FOR THE LEEU-TAAIBOSCHSPRUIT INDUSTRIAL COMPLEX SITUATED WITHIN THE VAAL BARRAGE CATCHMENT: VOLUME 2

Vaal Barrage DSS User Guide

Report

to the Water Research Commission

by

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AEV	Acute effect value
CEV	Chronic effect value
DSS	Decision support system
RQO	Resource quality objective
SPATSIM	Spatial and Time Series Information Modelling
TDS	Total dissolved solids
TSS	Total suspended solids
WQSAM	Water Quality Systems Assessment Model
WRPM	Water Resources Planning Model
WUL	Water use license

CHAPTER 1: INTRODUCTION

The material presented here is a simple manual on how one can use the Vaal Barrage decision support system (DSS) to assess the effect of changing water use license (WUL) return flows on the likelihood of achieving resource quality objectives (RQOs) or other instream water quality targets in the Vaal Barrage region. A simple explanation of how the DSS works is followed by providing instructions on how to install it, and providing an explanation of navigation and conventions in the software. This is followed by three examples of how the DSS might be applied in the Vaal Barrage catchment. The text covering the full introduction, explanation, calibration and rationale for the Vaal Barrage DSS is presented separately in Slaughter et al. (2019).

CHAPTER 2: A BRIEF OVERVIEW OF THE VAAL BARRAGE DECISION SUPPORT SYSTEM'S FUNCTIONALITY – WHAT THE DIFFERENT PARTS OF THE MODELLING SYSTEM DO

This section shows, in a simple way, how the Vaal Barrage DSS links a water model, such as the Water Resources Planning Model (WRPM), the Spatial and Time Series Information Modelling (SPATSIM) and the Water Quality Systems Assessment Model (WQSAM), to model water quality in the barrage area. The WRPM is used to simulate flow in the Vaal Barrage according to the systems diagram shown in Figure 2.1. Monthly incremental or natural flow is simulated by a hydrological model, usually the Pitman model, and then input into the WRPM at incremental flow nodes (indicated by the nodes with "UV" prefixes in Figure 2.1). The WRPM will have been calibrated using data such as monthly extractions, return flows and reservoir operations in the system to allow the model to simulate monthly flow. The flows from the WRPM are input into SPATSIM, a geo-referenced hydrological modelling platform. SPATSIM also has a feature called "nodes", which will follow the same system structure as the WRPM (See Figure 3.3 and Figure 3.4). The node feature will have attributes, some of which will correspond to the flows generated by the WRPM. For example, the WRPM simulates monthly estimates of return flows, abstractions, reservoir volumes and channel flows, and the node feature in SPATSIM will have attributes that directly correspond to these WRPM flows, and in which these WRPM flows are entered.

The WQSAM and the Vaal Barrage DSS are then linked to SPATSIM by following the same system structure in a node-linked manner. For example, see the list of nodes in the left-hand side of the water quality modelling screen of the DSS (Figure 4.6) – these can be located in the system diagram (Figure 2.1). WQSAM reads in the node attributes from SPATSIM. However, WQSAM requires additional attributes related to daily flows and water quality. This is why, under the node feature in SPATSIM, one can find numerous attributes relating to monthly flows, daily flows, water quality parameters, observed water quality and simulated water quality. SPATSIM essentially acts as a database for WQSAM and the Vaal Barrage DSS, with the water quality models reading and writing data from and to SPATSIM. The WQSAM implements a monthly to daily flow disaggregation, thereby disaggregating monthly flows generated by the WRPM into daily flows. The WQSAM is also used to calibrate water quality simulations against any observed water quality data in the Vaal Barrage, and accounts for more complex water quality processes, such as algal growth, water temperature, decomposition and settling. The decision was taken to separate the Vaal Barrage DSS from the WQSAM, essentially because users of the DSS would only be interested in investigating the effects of WULs on water quality in the Vaal Barrage. The additional functionality of WQSAM may then act to confuse users. The Vaal Barrage DSS essentially uses the same system structure as WQSAM and can read in calibrated water quality simulations. The only water quality processes the Vaal Barrage DSS represents are the effects of point and non-point sources of pollutants on water quality. In addition, the Vaal Barrage DSS allows the setting of RQOs or other instream goals for particular water quality variables and for particular nodes, and provides an intuitive method of comparing the simulated water quality to the RQOs, goals or guidelines in a way that allows users to estimate risk.

The Vaal Barrage DSS broadly has four types of nodes. The "UV" nodes are essentially nodes that receive incremental or "natural" flow. Users can only change non-point inputs of water quality loads at these nodes. It is recommended that users who are only interested in WULs should not change any of the calibrated parameters for the UV nodes.

The “DD” nodes are dummy dam nodes, and represent the approach taken in the WRPM process of accumulating several distributed water storages in a catchment into a single “dummy dam” for convenience. None of the dummy dam nodes in the Vaal Barrage DSS are of any consequence for simulating water quality in the catchment or for investigating WULs and RQOs. It is therefore recommended that users should not change any of the parameters for the dummy dams.

The third type of node, often but not always with the prefix “Node_”, represents links in the catchment and positions in which there is observed data against which model simulations can be compared to observed water quality data. These nodes may also contain points of wastewater discharge, which can be directly linked to WULs. Figure 2.1 provides an indication of where these point sources are positioned in the catchment, as well as a description of the origin of the point source. The pollutant concentrations of these point sources can be changed in the respective nodes, and can be directly linked to WULs.

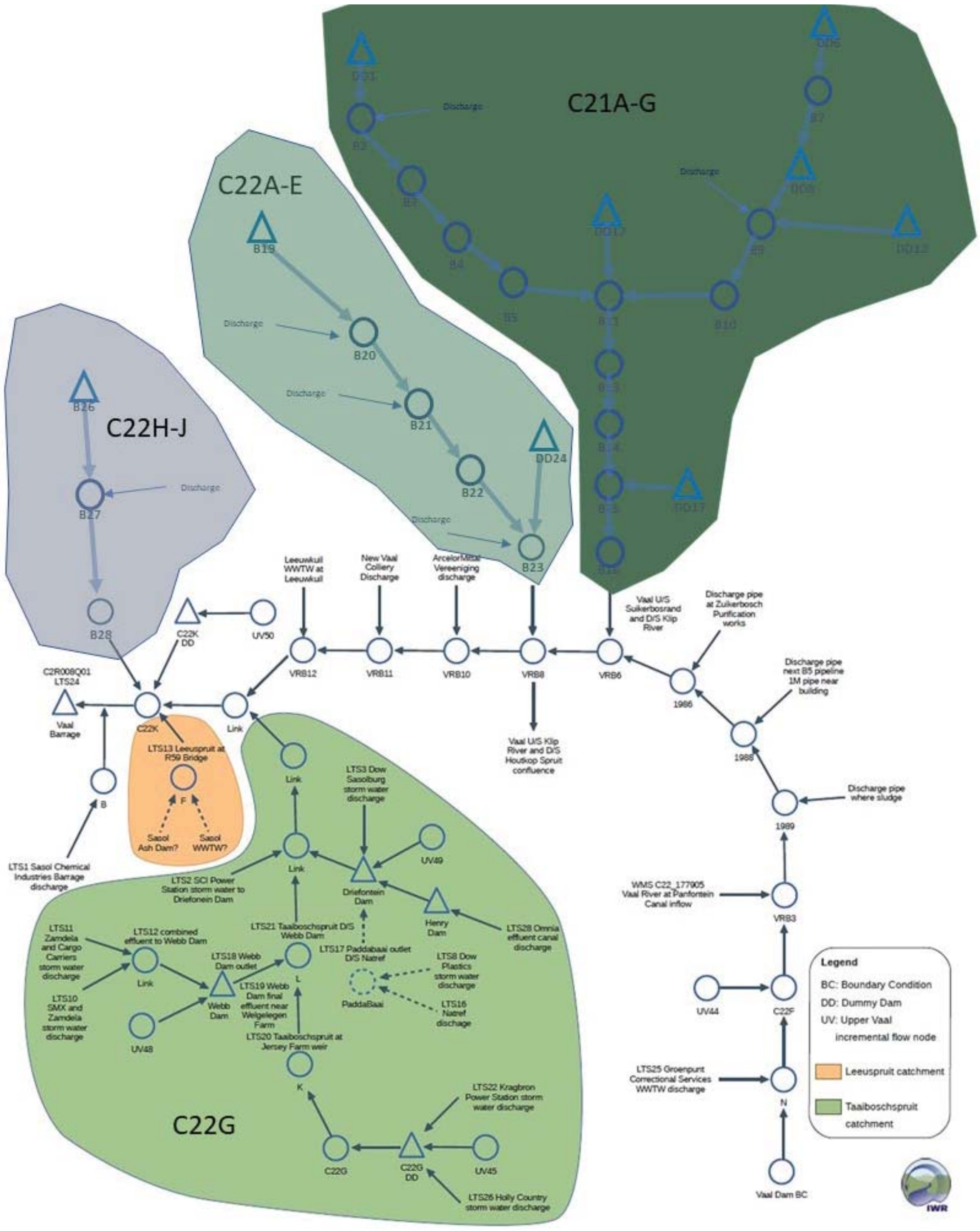

Figure 2.1: Systems diagram of the Vaal Barrage catchment showing modelled nodes. The diagram can be viewed by clicking on the “view barrage” button in the DSS.

The fourth type of node represents dams. There is a limited number of dams in the catchment, with the Vaal Barrage representing the most important one. Dams can and often also do indicate points of effluent return flow. Therefore, users may want to change the concentrations of point sources into these dam nodes, which they can similarly link to the WULs.

It is important to stress the flow directionality of the Vaal Barrage system in the DSS. The Vaal Barrage DSS reflects the flow of water in the Vaal Barrage from upstream to downstream. The direction of flow is indicated in Figure 2.1 by the direction of the arrows linking the nodes. This flow directionality is important when one considers the impacts of upstream stakeholders on downstream stakeholders. For example, the release of the effluent of all users in the Vaal Barrage catchment will have an effect on the water quality of the Vaal Barrage. In contrast, at Node B23 within the Upper Suikerbos, there will be only a few point sources upstream of this point that affect the water quality at Node B32.

The full introduction, explanation, calibration and rationale for the Vaal Barrage DSS is presented in Slaughter et al. (2019). The project reference group provided guidance throughout on the DSS design and implementation.

CHAPTER 3: OPENING THE VAAL BARRAGE APPLICATION IN SPATSIM

Once the user has downloaded and installed SPATSIM following the installation guide at <https://www.ru.ac.za/iwr/research/software/spatsim/>, the icon shown in Figure 3.1 should appear on their computer desktop. Now they will download the Vaal Barrage DSS application from <https://www.ru.ac.za/iwr/research/software/spatsim/> and install it, following the install prompts. Once both SPATSIM and the Vaal Barrage DSS are installed, the user will double click on the SPATSIM icon.

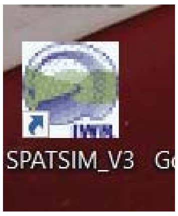

Figure 3.1: The SPATSIM icon on the computer desktop

The SPATSIM launch screen shown in Figure 3.2 will appear. The user's particular SPATSIM installation will likely only show a few applications. If one has installed the Vaal Barrage DSS properly, one should see the "barrage" application as a choice. To run SPATSIM with the Vaal Barrage application, click on the option and then the "select" button.

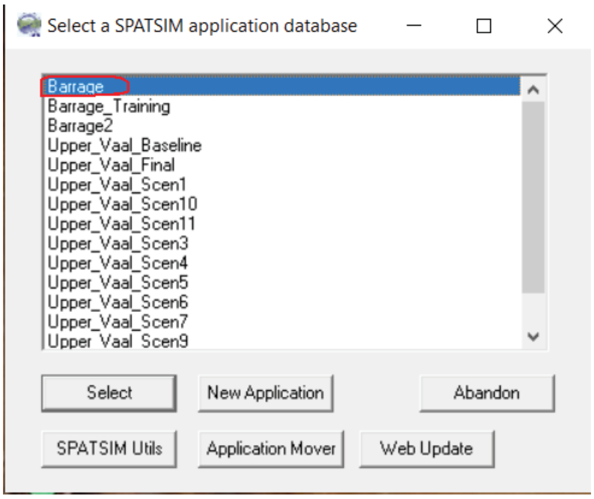

Figure 3.2: The SPATSIM launch screen showing the available applications. To run the Vaal Barrage DSS, click on the "barrage" application and the "select" button.

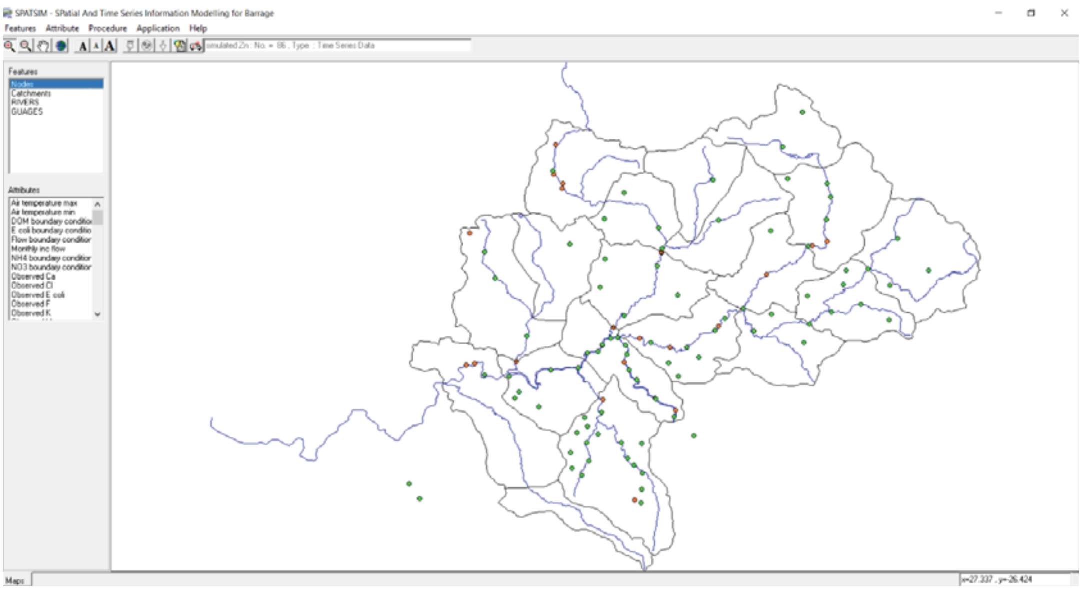

Figure 3.3: The SPATSIM application showing the Vaal Barrage application

SPATSIM should open showing the Vaal Barrage application as in Figure 3.3. The main screen shows geographic features linked to shape files, which are listed in the top left-hand box. The Vaal Barrage application has been installed with features already added. However, new features can be added as shape files (see the SPATSIM user manual for instructions). Features can have multiple attributes. For example, the “node” feature has many attributes, as listed in the left-hand lower box, that are required for simulating the water quality of the Vaal Barrage. As shown in Figure 3.4, one can switch labels for different features on and off, and change their size (see the SPATSIM user manual). One can also zoom in and out of features or pan to different areas.

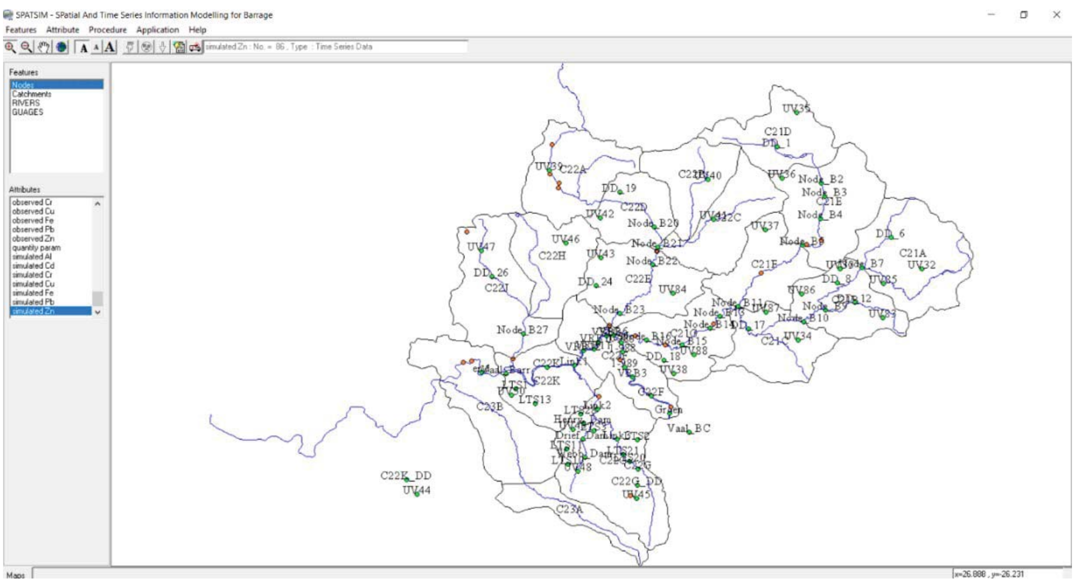

Figure 3.4: The Vaal Barrage application in SPATSIM showing labels for the “node” and “catchments” features

CHAPTER 4: RUNNING THE VAAL BARRAGE DSS

The Vaal Barrage DSS can be run through two different methods. The user can run the DSS from within SPATSIM by clicking on "application" → "run process" → "directly", as shown in Figure 4.1. One will then see the list of possible models to run as shown in the left-hand image in Figure 4.2. To run the DSS, double click on "barrage water quality DSS linked to RQOs".

Alternatively, users can double click on the icon shown in the right-hand side of Figure 4.2, which should appear on their desktop, provided the Vaal Barrage DSS has been installed correctly. This option allows users of the Vaal Barrage DSS to avoid starting SPATSIM altogether, although SPATSIM will still need to be installed.

The Vaal Barrage DSS launch screen, as shown in Figure 4.3, should appear. The latest DSS run will be the second in the list. To run the DSS, select the second run, click "read data" and then "run model".

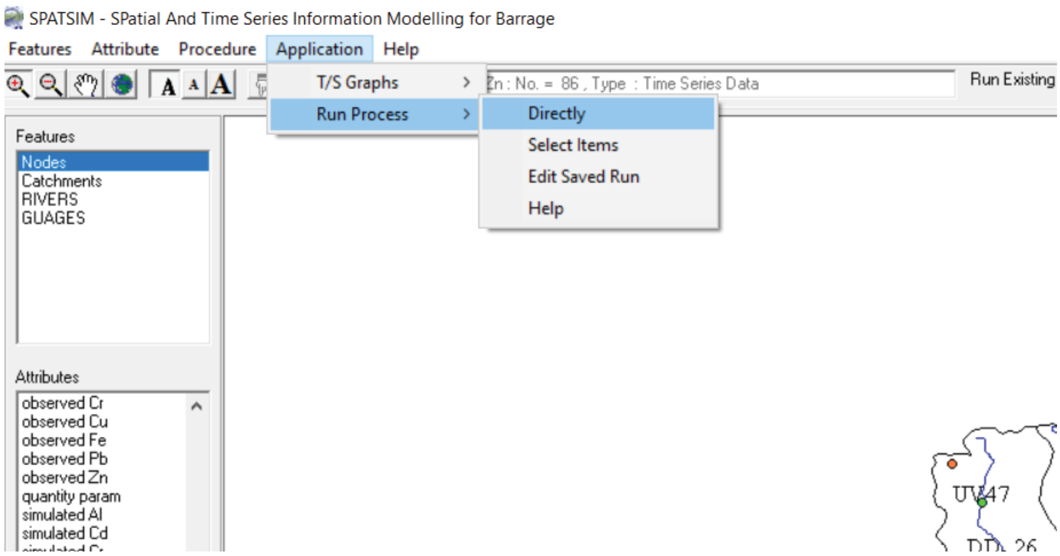

Figure 4.1: Process for running a model directly from within SPATSIM

Figure 1.2: The alternative methods of running the Vaal Barrage DSS: 1) the left-hand image shows the choice of models by selecting to run a model directly from SPATSIM following the directions in Figure 4.1. Choose the "barrage water quality DSS linked to RQOs" and double click on it; 2) Look for the Vaal Barrage DSS icon directly on the desktop and double click on the icon.

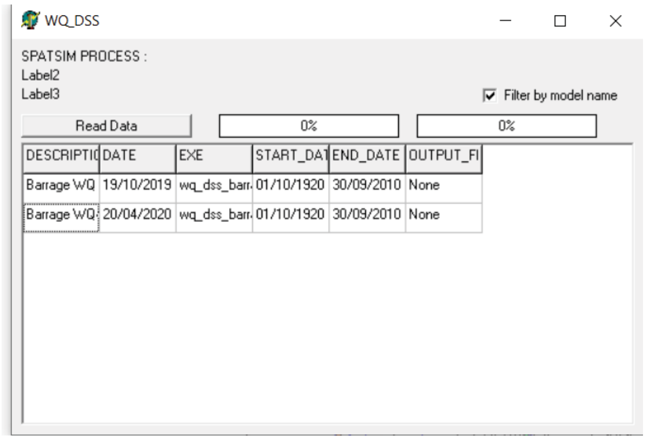

Figure 4.3: The launch screen of the Vaal Barrage DSS showing different model runs. To run the latest DSS, choose the second in the list, click on "read data" and then on "run model".

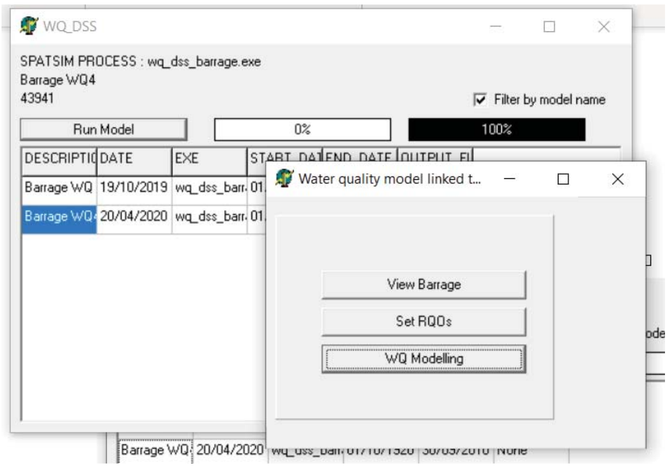

Figure 4.4: The features screen of the Vaal Barrage DSS. Three main different functions are available: "view barrage" will show a systems diagram of the Vaal Barrage; "set RQOs" is a screen that allows users to set RQOs, goals or other guidelines for different positions in the catchment; "WQ modelling" is a screen that allows the setting of pollutant loads and viewing of model simulations in relation to the RQOs for different positions in the catchment.

CHAPTER 5: NAVIGATING THROUGH THE VAAL BARRAGE DSS

Clicking on the “view barrage” button will show a systems diagram of the Vaal Barrage catchment, showing modelled nodes (Figure 2.1). This screen allows users to geo-reference different modelled nodes, and also shows how nodes are connected, illustrating how water quality at upstream nodes will affect the water quality of downstream nodes.

Clicking on the “set RQOs” button will bring up the screen shown in Figure 5.1. Users can set RQOs, goals or guidelines for any nodes. This allows maximum flexibility for investigating different scenarios where RQOs could possibly be changed and also allows for updates to RQOs. To set RQOs for a particular node and a particular water quality variable, click on the desired node in the left-hand list, and enter a number for a numerical limit and the 95th percentile for the desired water quality variable. Please make sure to click the “save RQOs for node” before exiting the screen or selecting a different node. Please also ensure that a valid number is entered and that the units are correct.

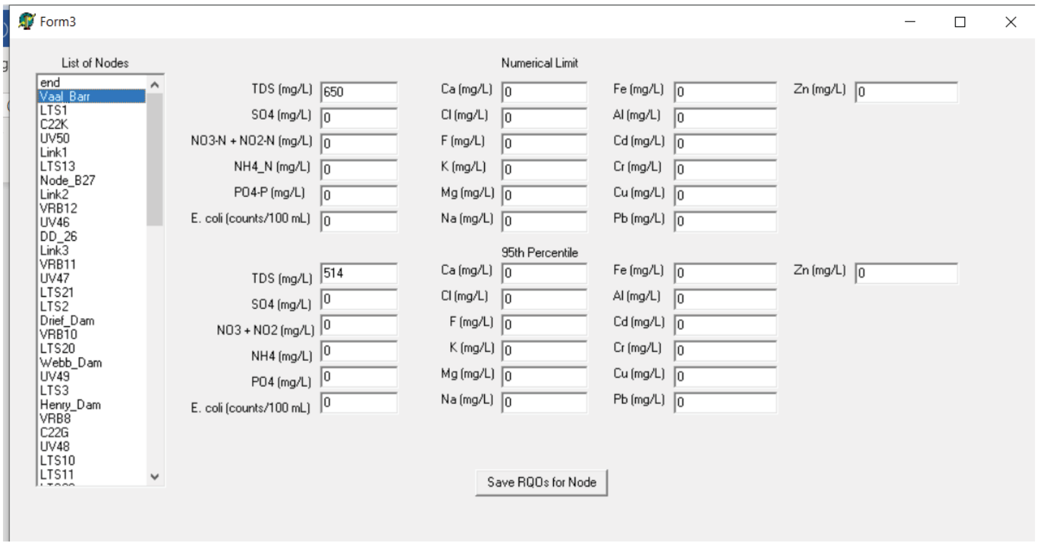

Figure 5.1: Screen for setting RQOs for different modelled nodes. This screen can be accessed by clicking on the “set RQOs” button. For each node, two RQOs can be set: a numerical limit and a 95th percentile.

Most of the functionality of the DSS is in the water quality modelling screen, as shown in Figure 5.2. This can be accessed by clicking on the “WQ modelling” button. This screen allows point and non-point pollutant inputs to be changed for different parts of the catchment. This screen also allows model simulations to be compared with observed data (where available), as well as RQOs for different parts of the catchment.

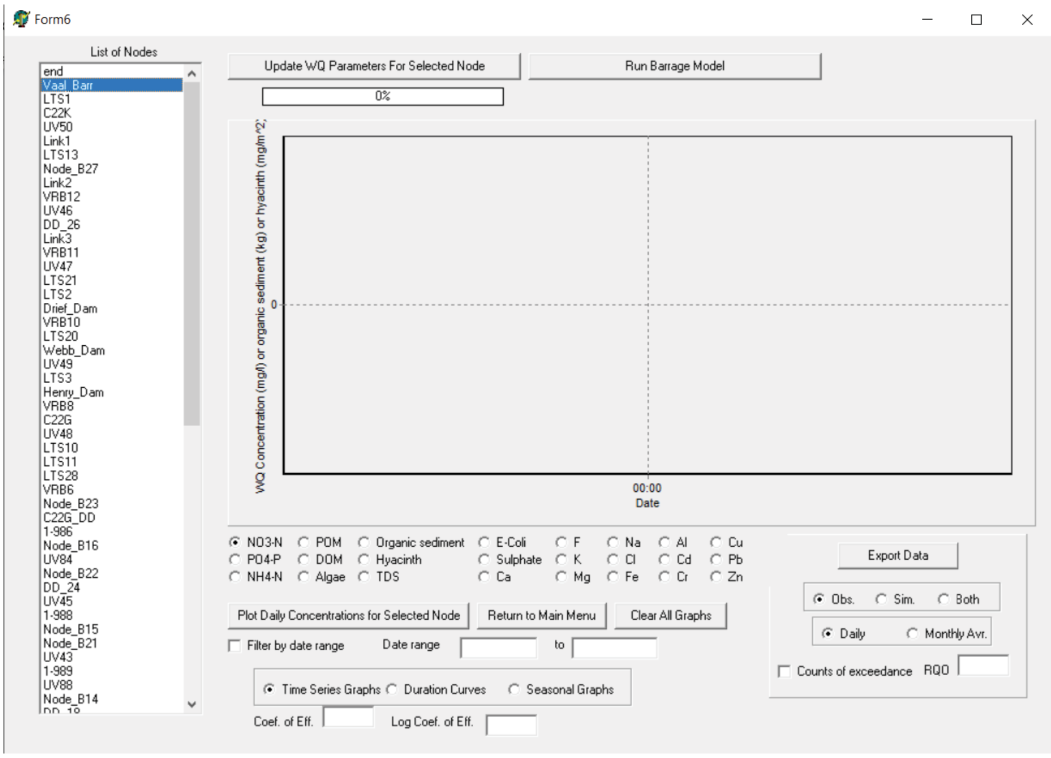

Figure 2 The water quality modelling screen of the Vaal Barrage DSS. This screen can be accessed by clicking on the "WQ modelling" button.

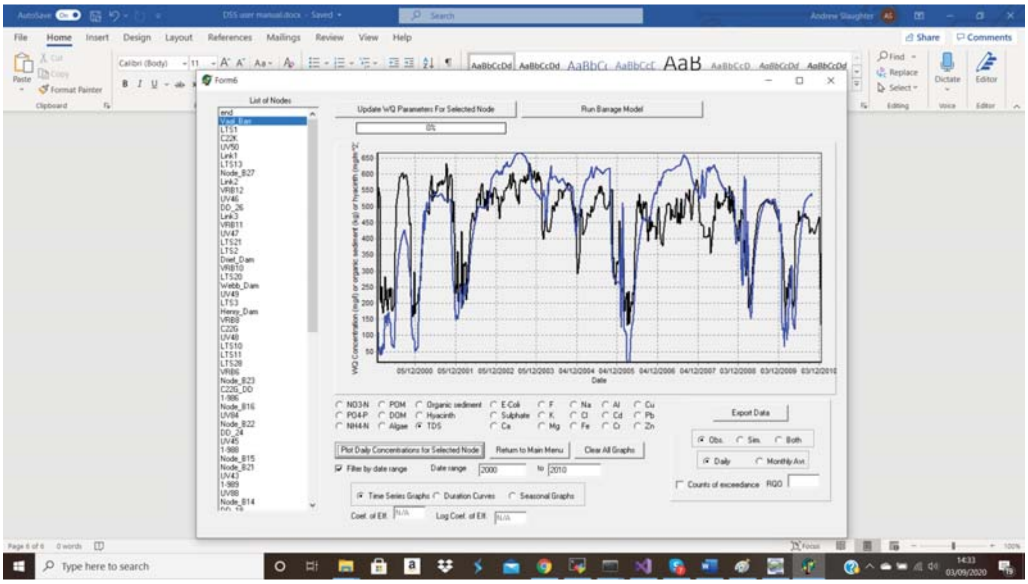

Figure 3 Water quality modelling screen of the Vaal Barrage DSS showing simulations of total suspended solids for the Vaal Barrage as compared to available observed data for 2000–2010 as a time series. Modelled data is blue, and observed data is black.

Water quality simulations can be compared to observed data for different parts of the catchment. For example, as shown in Figure 5.3, time series simulations can be compared to available observed data. Select the node of interest in the left-hand list, then click the radio button at the bottom of the panel for the water quality variable of interest. You can either look at the entire simulation period (1920–2010) or at a subset of the simulations.

To choose a subset, click on the “filter by date range” check the box and enter the start and end dates as year ranges, for example, 2000–2010. Since the majority of observed data is available from 2010, it is recommended to filter the data range for 2000–2010 when comparing simulated and observed data.

Model simulations can also be displayed and compared against observed data as frequency distributions by selecting the “duration curves” button at the bottom of the panel instead of the “time series graphs” button. The baseline Vaal Barrage application has already been calibrated against the observed data, which was done through a visual comparison of observed and simulated data as frequency distributions, shown as the black and blue lines in Figure 5.4, respectively. By plotting as a frequency distribution, the user can also view the RQOs for a particular node (if set) for comparison against observed and simulated data. For example, the numerical limit and 95th percentile for the Vaal Barrage node are shown as the yellow and red lines in Figure 5.4, respectively. To interpret the water quality of the node against the RQO, assess where the yellow and red lines cross the x-axis of the graph. This indicates the percentage time during which water quality at that node exceeds the RQO. For example, as shown in Figure 5.4, total dissolved solids (TDS) at the Vaal Barrage exceed the 95th RQO around 54% of the time. Ideally, the red line should cross the x-axis at around the 5% point. Although these RQOs are hypothetical, in this case, the model is showing that TDS at the barrage far exceed the 95% RQO, although the numerical limit is exceeded only around 3% of the time.

Point and non-point loads for different parts of the catchment can be set in this panel. Non-point loads are associated with incremental flow (natural flow) nodes, which, in the model, have a “UV” prefix in the node name, e.g. UV45, etc. For example, as shown in Figure 5.5, to change the non-point loads for UV35, select the node in the left-hand list and then click on the “update WQ parameters for selected node” at the top of the panel. Then select the radio button for the water quality variable for which one wants to change non-point loads. For non-point loads, one can set concentrations for surface water, interflow and groundwater flow, indicated by “SF signature”, “IF signature” and “GF signature” in Figure 5.5, respectively. Concentrations are set in mg/ℓ. Typically, though, users should avoid changing these parameters as they are essential for model calibration and are not relevant for WULs that are associated with point sources. Users should enter relevant values in the fields and click the “save” button.

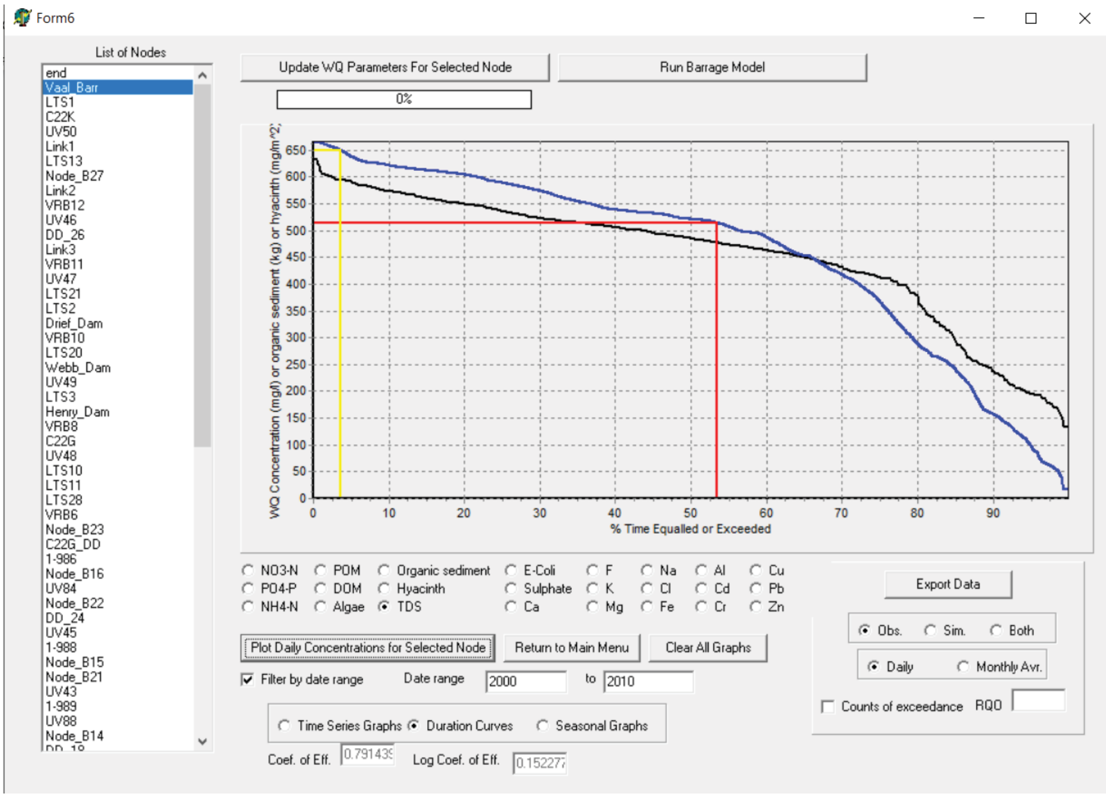

Figure 5.4: Water quality modelling screen of the Vaal Barrage DSS showing simulations of total suspended solids for the Vaal Barrage compared to available observed data for 2000–2010 as frequency distributions. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

Users can also change loads for point sources at different parts in the catchment. The user will need to select a node for which there is a point source from the left-hand list in the panel, as shown in Figure 5.6, and then click on the “update WQ parameters for selected node” at the top of the panel. The panel for changing the point source and non-point source concentrations will then appear. The DSS currently allows concentrations for up to two point sources per node to be set. The concentrations are in mg/ℓ. Importantly, the point source concentrations can be directly linked to water use licenses for particular stakeholders. Users should enter relevant values in the fields and click the “save” button.

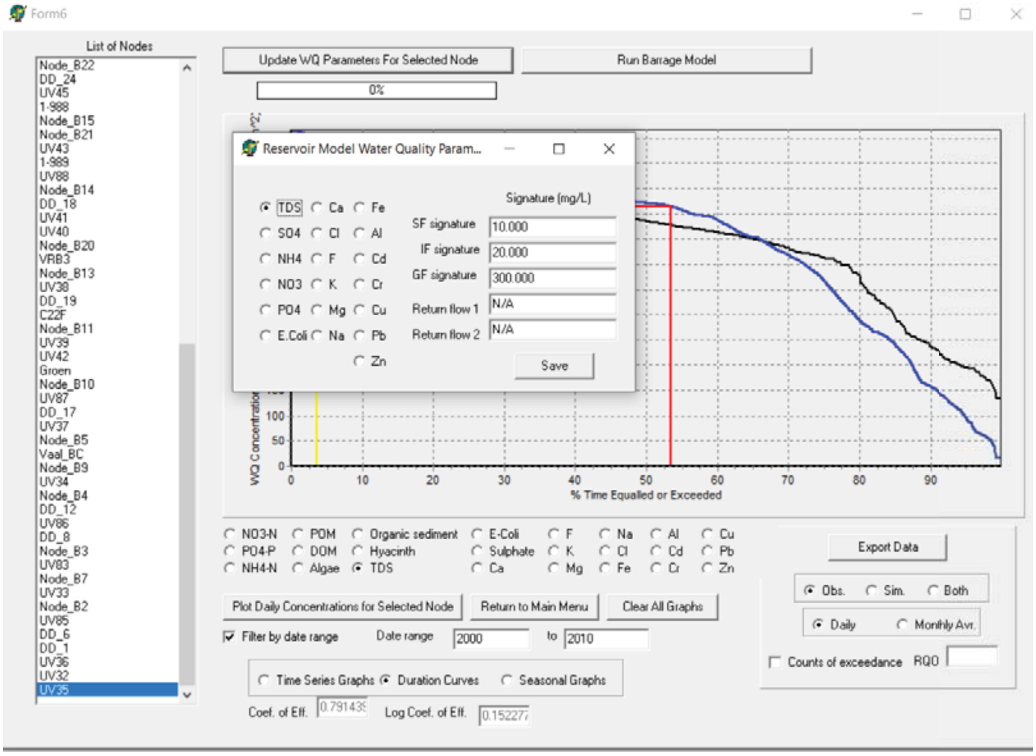

Figure 5.5: Screen within the Vaal Barrage DSS used to change point and non-point inputs for different variables for a particular node. In this example, an incremental flow node is selected, which is why non-point loads can be adjusted. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

The results of changing point and non-point source concentrations in the model can be assessed by clicking on the “run barrage model” button at the top of the panel. For more information on this aspect of the model, see the section below.

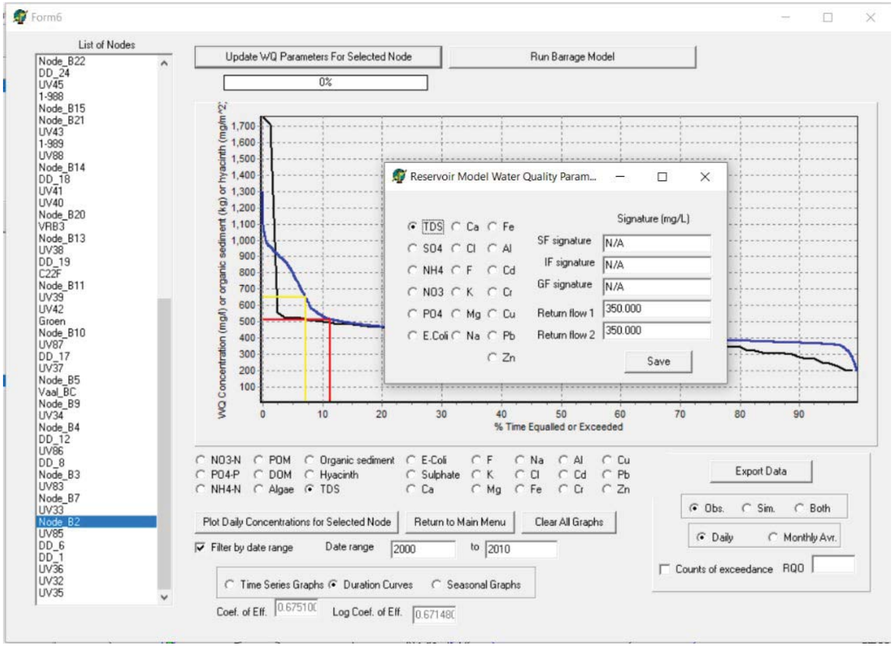

Figure 5.6: Screen within the Vaal Barrage DSS used to change point and non-point inputs for different variables for a particular node. In this example, a return flow node is selected, which is why point source loads can be adjusted. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

CHAPTER 6: SOME SIMPLE EXAMPLES OF SCENARIOS IN THE DECISION SUPPORT SYSTEM

6.1 EXAMPLE 1: INVESTIGATING EFFECTS OF SALT LOADS ON DOWNSTREAM RESOURCE QUALITY OBJECTIVES IN THE BLESBOKSPRUIT

The effect of changing upstream loads on the water quality in the catchment can be investigated in the DSS by changing concentrations of point sources and re-running the model. A very simple example is presented below to illustrate this point. As shown in Figure 6.1, quaternary catchments C21D and C21E (Blesbokspruit) are upstream tributary catchments of the Vaal Barrage. In this section, the nodes UV35, UV36 and UV37 are nodes for incremental (natural) flow and would therefore contain parameters for non-point source loads for water quality variables. Node_B2 is a node in which there is a point source, i.e. a position in the catchment for which there is a WUL. Node_B5 is a position in the catchment for which there is observed data. One can also look at simulated water quality at this position to assess the impacts of the point source upstream at Node_B2. As shown in Figure 6.2, if one were to plot the frequency distributions for TDS at Node_B5, one can see the hypothetical RQOs set at this point in relation to observed and simulated data. It is clear that the simulated water quality exceeds the numerical limit and 95th percentile RQOs for 7% and 11% of the time, respectively.

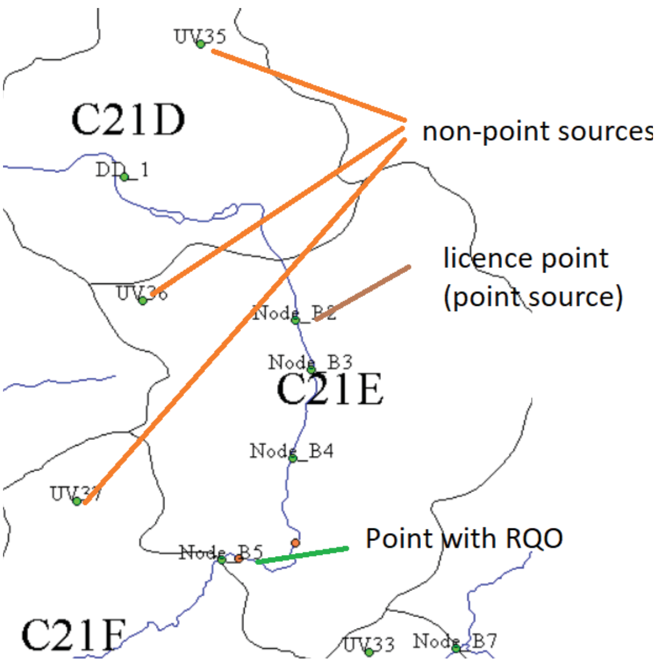

Figure 6.1: Subset of the Vaal Barrage catchment showing nodes selected to illustrate how the Vaal Barrage DSS can be used to investigate changes in upstream pollutant loads. UV35, UV36 and UV37 are nodes associated with incremental (natural) flow. Node_B2 is a node in which there is a return flow (WUL), Node_B5 will be the node for which simulated water quality will be compared to the RQO.

One could investigate how one can change licenses in the catchment to achieve TDS concentrations at Node_B5 that fall within the hypothetical RQOs. Users will primarily be interested in changing WULs, which are associated with point sources. There is one point source above Node_B5, situated at Node_B2. Therefore, one can investigate how the WUL at Node_B2 for TDS can be changed to achieve the desired water quality at Node_B5. As shown in Figure 6.3, the point source signature for TDS for both point sources (WULs) at Node_B2 are set to 350 mg/ℓ. As shown in Figure 6.4, one can change the point source signature for TDS at Node_B2 to 50 mg/ℓ, and then click on the “run barrage model” button at the top of the panel.

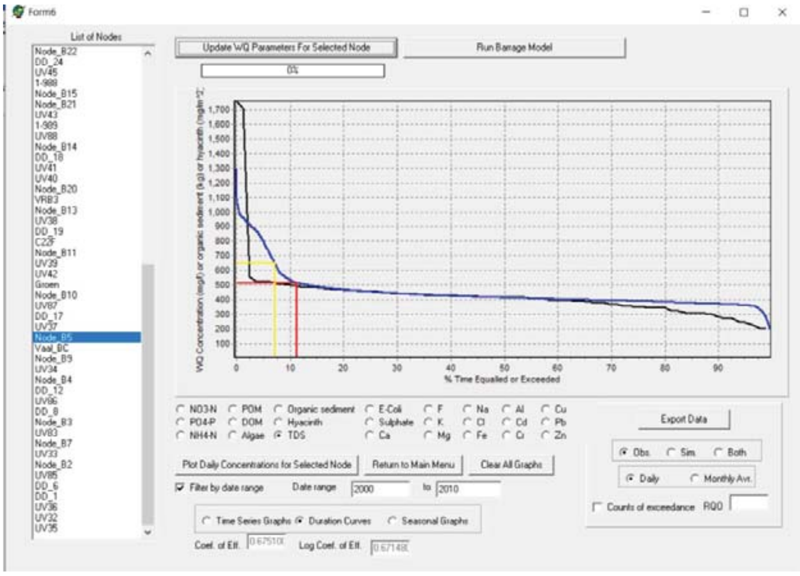

Figure 4 A comparison of model-simulated TDS with observed TDS at Node_B5 in the Vaal Barrage catchment as frequency distributions, shown in relation to the RQOs at this position. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

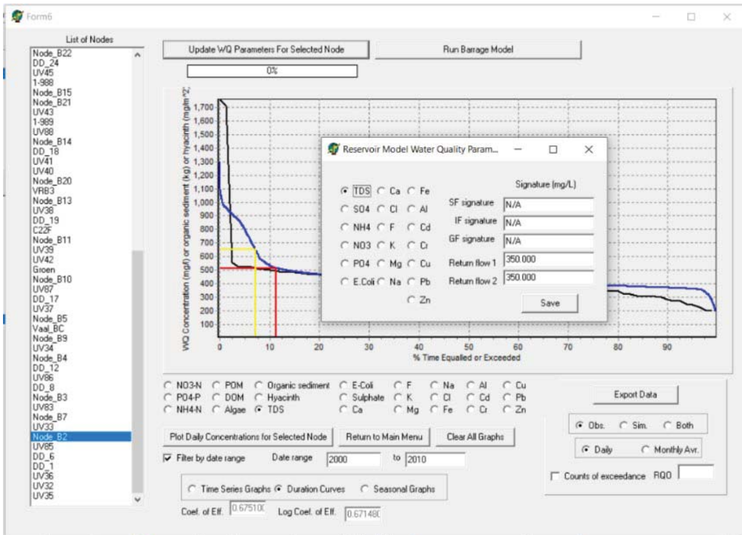

Figure 6.3: Panel for changing point and non-point source signatures for nodes in the Vaal Barrage DSS. In this example, the TDS point source signatures for TDS at Node_B2 are set to 350 mg/ℓ. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

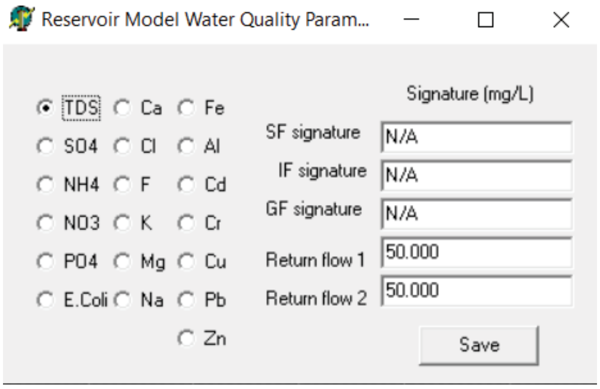

Figure 6.4: Panel for changing point and non-point source signatures for nodes in the Vaal Barrage DSS. In this example, the TDS point source signatures for TDS at Node_B2 are set to 50 mg/ℓ to investigate the resulting water quality downstream at Node_B5.

The progress bar at the top of the panel will show the status of the model simulation run. Once the model stops running, one can go back to Node_B5 and plot the frequency distribution for TDS. As shown in Figure 6.5, one can now see that the simulated data (blue line) does not match the observed data (black line). In addition, the numerical limit and 95th percentile RQOs are exceeded by the simulated data for around 5% and 7% of the time, respectively. In this case, it appears that the majority of the TDS load in this part of the catchment originates from non-point sources, and even greatly reducing the point sources upstream does not allow the simulated water quality to fall within the RQOs.

6.2 EXAMPLE 2: INVESTIGATING EFFECTS OF WATER USE LICENSES FOR FLUORIDE ON THE RESOURCE QUALITY OBJECTIVES IN THE UPPER SUIKERBOSRAND

To investigate the effect of the WULs on RQOs, one can – as a hypothetical example – look at Node B10 in the Upper Suikerbosrand at the outlet of quaternary catchment C21B (Figure 6.6). Node B9 immediately upstream of Node B10 is assigned a WUL for fluoride of 3 mg/ℓ. One can set the RQOs for fluoride in the catchment according to the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996), with the chronic effect value (CEV) and acute effect value (AEV) of 1.5 mg/ℓ and 2.54 mg/ℓ used to set the 95th percentile and numerical limit RQOs, respectively. Under the current WUL, the simulated fluoride at Node B10 falls within the RQOs (Figure 6.7), with the numerical limit (yellow line) not exceeded and the 95th percentile (red line) RQO exceeded only about 2% of the time. One can now see what can happen if an additional WUL for fluoride at Node B9 is set, also for a concentration of 3 mg/ℓ. The addition of a new WUL pushes simulated fluoride concentrations above the numerical limit and 95th percentile RQOs for about 3% and 7% of the time, respectively (Figure 6.8).

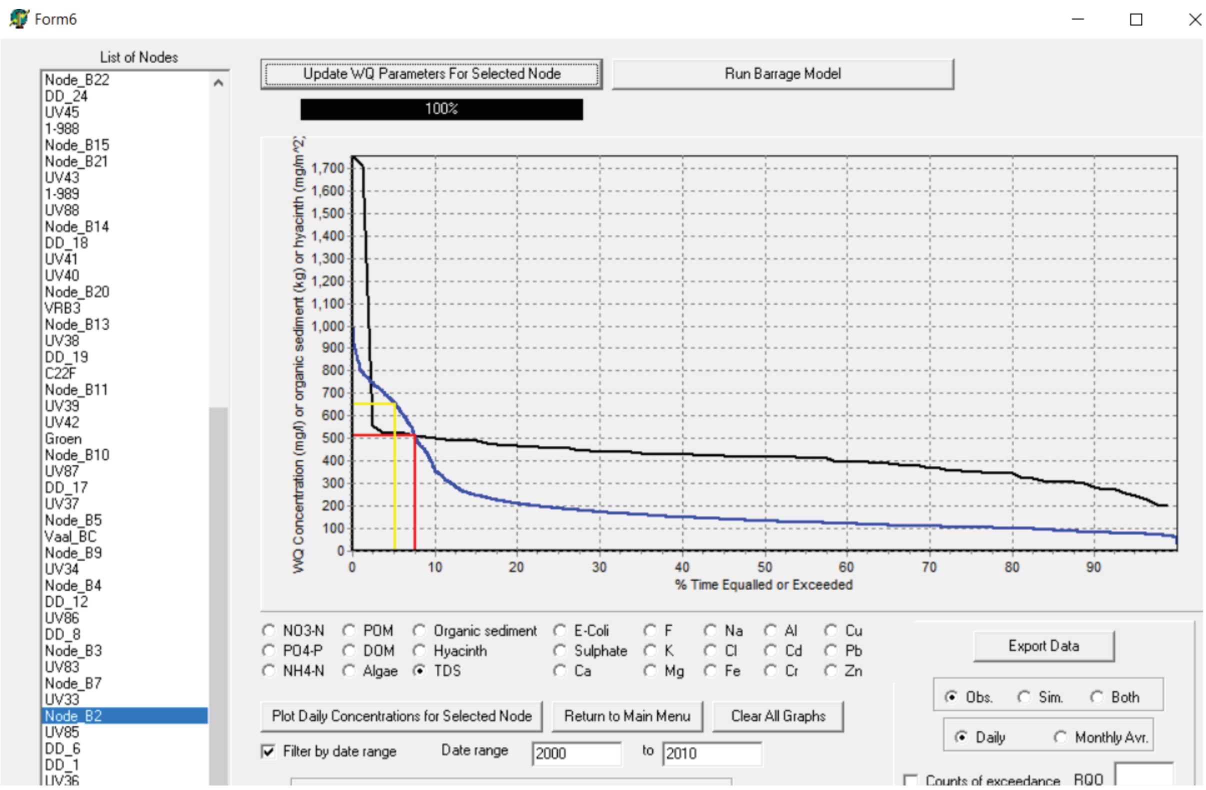

Figure 6.5: A comparison of model-simulated TDS with observed TDS at Node_B5 in the Vaal Barrage catchment as frequency distributions, shown in relation to the RQOs at this position, after adjusting point source inputs of TDS upstream. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

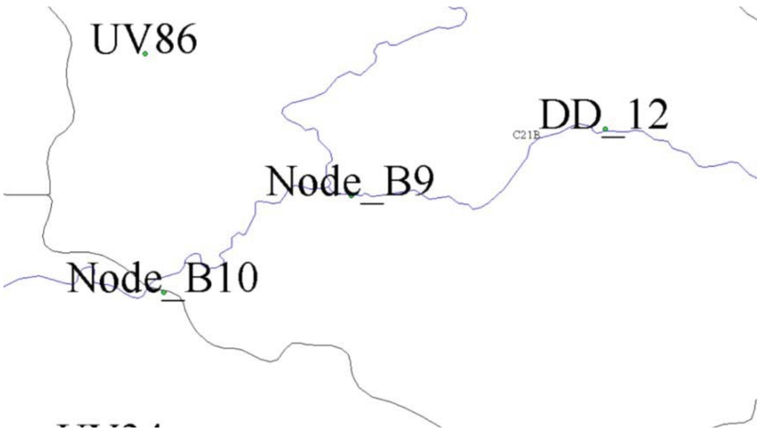

Figure 6.6: Upper Suikerbosrand subcatchment of the Vaal Barrage catchment showing nodes selected to illustrate how the Vaal Barrage DSS can be used to investigate the effect of WULs on an RQO. Here, RQOs for fluoride are set at Node B10 according to the South African Water Quality Guidelines (DWAF, 1996). A WUL is set at Node B9 upstream. An additional WUL is added upstream, and a comparison between fluoride concentrations and the RQO is made before and after the addition.

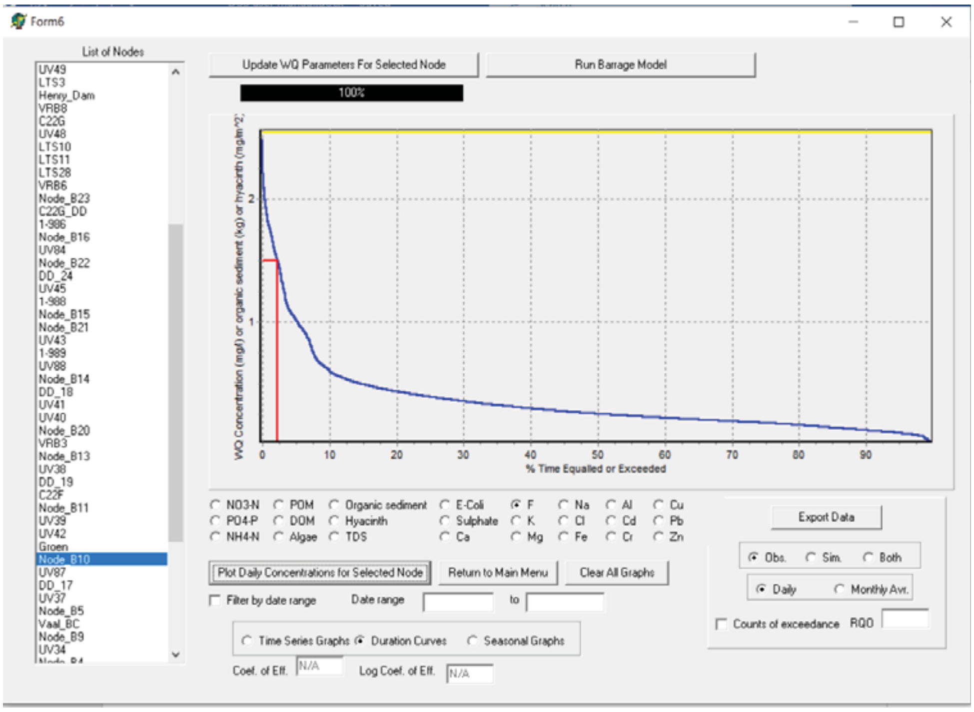

Figure 6.7: A comparison of model-simulated fluoride with the RQOs for fluoride at Node_B10 in the Upper Suikerbosrand under the current WUL for fluoride immediately upstream. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

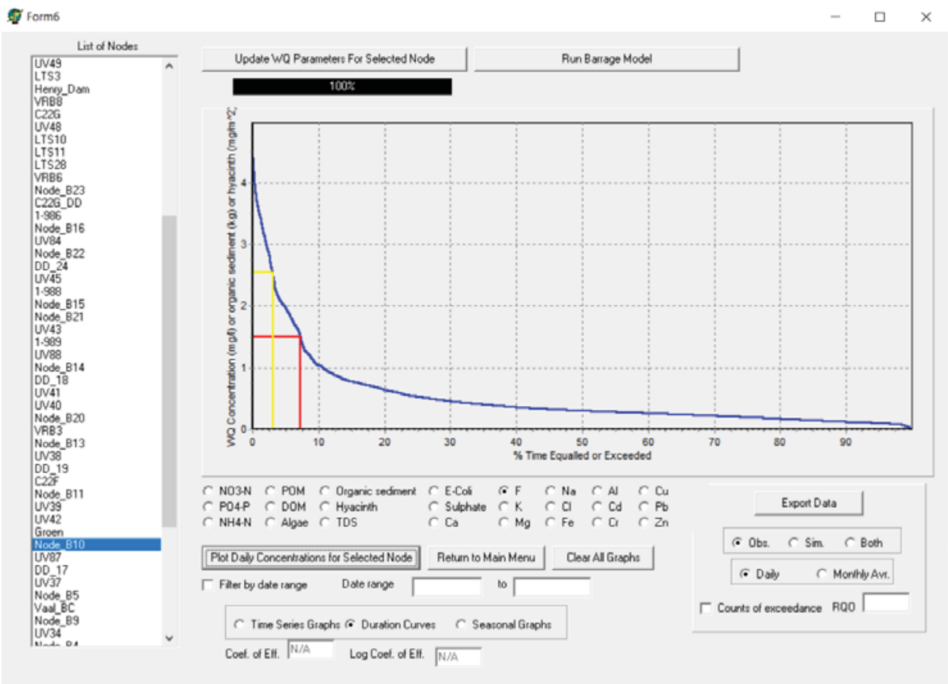

Figure 6.8: A comparison of model-simulated fluoride with the RQOs for fluoride at Node_B10 in the Upper Suikerbosrand under a new WUL for fluoride immediately upstream. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

6.3 EXAMPLE 3: SETTING A WATER USE LICENSE FOR COPPER IN THE UPPER SUIKERBOSRAND

The WULs for particular water quality variables can be set using the DSS. To demonstrate, one can again use the example of the Upper Suikerbosrand. One can set the numerical limit and 95th percentile RQOs for copper at Node B10 according to the CEV and AEV of the Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996) of 4.6 µg/ℓ and 1.5 µg/ℓ, respectively. An appropriate WUL for copper at the upstream Node B9 can then be investigated by setting the return flow concentration for copper, running the model, and assessing the simulated copper against the RQOs at Node 10. As shown in Figure 6.9, if one sets the WUL for copper at Node 9 to 4 µg/ℓ, the simulated water quality at the downstream Node B10 does not exceed the numerical limit RQO, and exceeds the 95th percentile RQO exactly 5% of the time, thereby indicating that a WUL of 4 µg/ℓ for copper would be appropriate for this part of the catchment.

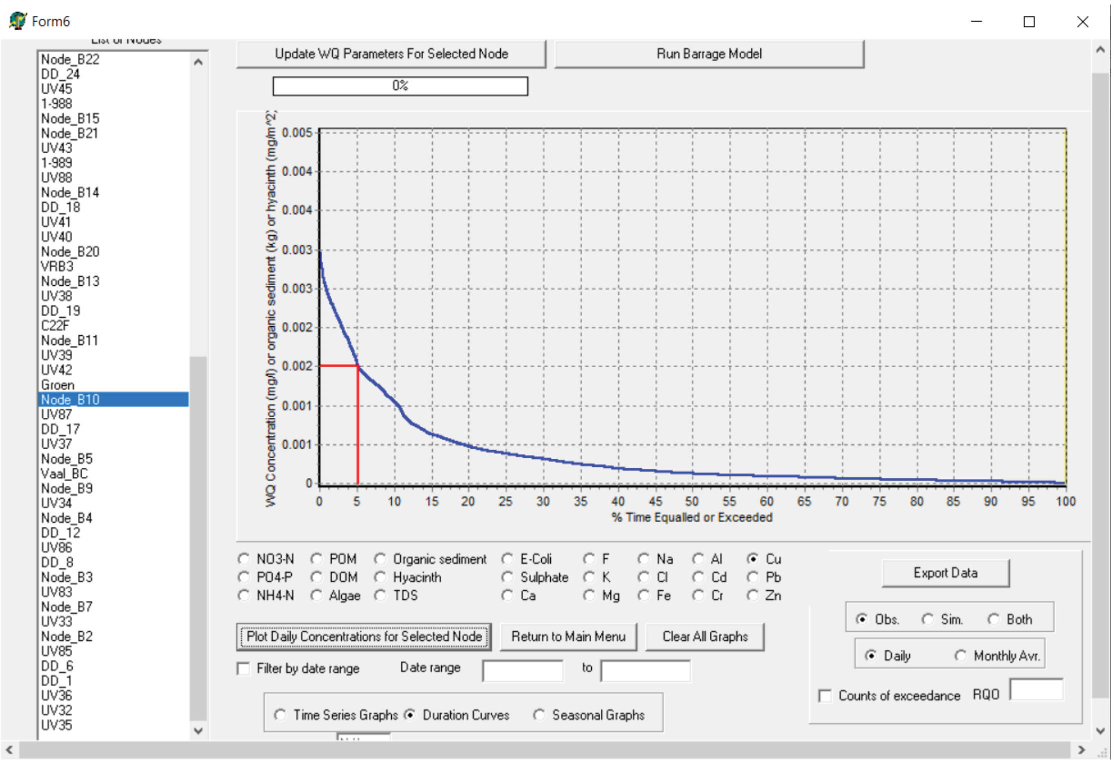

Figure 6.9: A comparison of model-simulated copper with the RQOs for copper at Node_B10 in the Upper Suikerbosrand under a WUL for copper immediately upstream. Modelled data is blue, observed data is black, and RQO numerical limits are yellow, while 95th percentiles are red.

REFERENCES

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