DESGNING WATER DISTRIBUTION NETWORK FOR SOKOTO

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Abstract

The research is on designing water distribution network that best represent the hydraulic and water quality modeling realities in Sokoto network area and its environs. Residual chlorine observed results at thirty (30) different locations were determined in the network area.

A well calibrated and validated, ideal model for Sokoto water distribution network, was developed after series of adjustments, tinkering and tweaking of the hydraulic simulation components and the water quality simulation variables. The network sample calibration locations are 31, 9, 8, 34, 24, 20, 22, 29, 19 and 16. The network sample validation locations are 18, 21, 17, 25, 23, 30, 27, and 11.Sokoto network system calibration and validation of the predicted and observed data was computed and gives calibration correlation R^2 to be 0.908 and validation correlation R^2 to be 0.648. Validated Epanet 2.0 Sokoto WDS average k_b at the pipe wall is 55.08%, at the bulk of flow is 12.28% and at the system tanks is 32.64%. It Infer that Sokoto WDN chlorine decay is mostly concentrated at the pipe walls and at the tank, with the least decay occurring at the bulk of flow.

Keywords: Water Distribution Network, Bulk and Wall decay coefficients, Calibration and Validation

1.0 INTRODUCTION

A distribution network or a pipe network is the grid formed by the nodes, links and loops, if any. In practice it also contains reservoirs (also known as tanks), pumps, valves and other accessories. Distribution of water refers to the actual delivery of treated water to homes, business, and industries. (It is axiomatic that no water should be delivered without treatment), before water can be treated and distributed, it has to be collected from a water supply source and transmitted to a water treatment plant (Arcadio and Gregoria, 2008).

A real life water distribution network is extremely complex involving large number of different components. It is extremely difficult, or rather impossible, to consider all such components – right from the source nodes to the tapping points of the consumers – in the analysis of a water distribution network. It is therefore customary to prepare a mathematical model of the network and analyze it. The mathematical model of a water distribution is a skeletal network primarily consisting of node and links. The network includes all service and balancing reservoirs, pumping stations, links in the main direction of flow and loop-forming links. Bulk consumptions are considered individually while small demands such as domestic consumption are lumped together and are assumed to occur at demand nodes. Depending on the topography, booster pumps and pressure-reducing valves are included in the model. Check valves, if necessary, are also included. While preparing a mathematical model of a water distribution network, it must be seen that the model is not too elaborate to pose problems working on it with the available computer, not too sketchy to distort the behavior to unacceptable limits. (Bhave and Gupta 2013)

The desired quantity of water to be supplied to the consumers at sufficient pressure is a product of a well-designed water distribution network. The design comprises of specifying the sizes of each components of the distribution network and verifying the accuracy and adequacy of the network (Mays, 2000). Optimal designs of water distribution systems have been significantly developed through consistent effort.

2.0 MATERIAL AND METHODS

2.1 Epanet 2.0 Model Setup for Sokoto Water Distribution Network

EPANET Models a water distribution system as a collection of links connected to nodes. The links represent pipes, pumps and control valves. The nodes represent junctions, tanks and reservoirs. Each one of these objects requires a basic input data for proper operation of the model.

Table 2.0: Input Properties for EPANET 2.0 Sokoto Model

S/N	PIPES ;ID	Node1	Node2	Length (m)	Diameter (mm)
1	1	39	45	1775	600
2	2	36	41	2000	600
3	3	40	46	1500	600
4	4	35	41	1775	450
5	5	38	45	1500	600
6	6	37	42	1995	375
7	8	48	32	30	100
8	10	43	33	30	100
9	11	32	8	850	350

10	12	8	15	950	200
11	13	15	16	825	200
12	14	16	17	700	200
13	15	15	10	850	200
14	18	26	25	600	200
15	19	24	25	500	200
16	20	24	23	500	200
17	21	8	18	950	200
18	23	8	20	950	200
19	24	8	21	995	200
20	25	33	14	900	300
21	26	10	9	700	200
22	28	14	22	900	150
23	29	14	13	600	300
24	30	27	11	450	200
25	31	11	12	400	200
26	32	13	34	850	200
27	33	34	12	650	200
28	34	32	23	900	200
29	35	33	28	650	300
30	36	28	29	600	250
31	37	29	30	900	200
32	38	30	31	900	150
33	39	18	19	950	200
34	42	47	32	30	100
35	45	44	33	30	100

2.2 EPANET Project Setup for Sokoto Water Distribution Network

The first task is to create a new project in EPANET and make sure that certain default options are selected. launch EPANET, if already running select file >> new (from the menu bar) to create a new project. Then select project >> defaultsto open the dialog form shown in figure 2.0. We use the dialog to have EPANET automatically label new objects with consecutive numbers starting from 1 as they are added to the network. On the ID Labels page of the dialog, all of the ID prefix fields were cleared and the ID Increment set to 1. Select the hydraulics page of the dialog and set it, to flow units of

GPM (gallons per minute). This implies that US customary units will be used for all other quantities as well as (length in feet, pipe diameter in inches, pressure in psi, etc.). Hazen - Williams (H-W) was selected as the headloss formula. Check the Save box at the bottom of the form before accepting, for future projects.

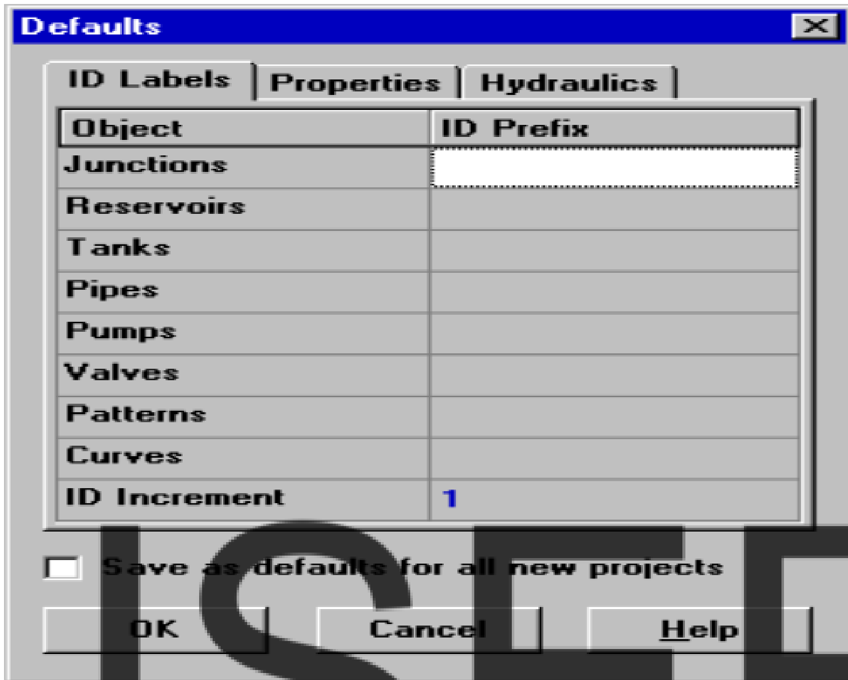


Figure 2.0: Project Dialog form

Next map display options was selected so that, as we add objects to the map, we will see their ID labels and symbols displayed, view >> optionsselected to bring up the map options dialog form. The notation page on this form was selected and checked, the settings is shown in figure 2.1, then switch to the Symbols page and check all the boxes. Okbutton was checked the choices accepted and the dialog box closed. Finally, before drawing the network, we ensure that the map scale settings are acceptable then, View >> Dimensions was selectedand it bring up the map dimensions dialog. Note the default dimensions assigned for any new project and click the OK button.

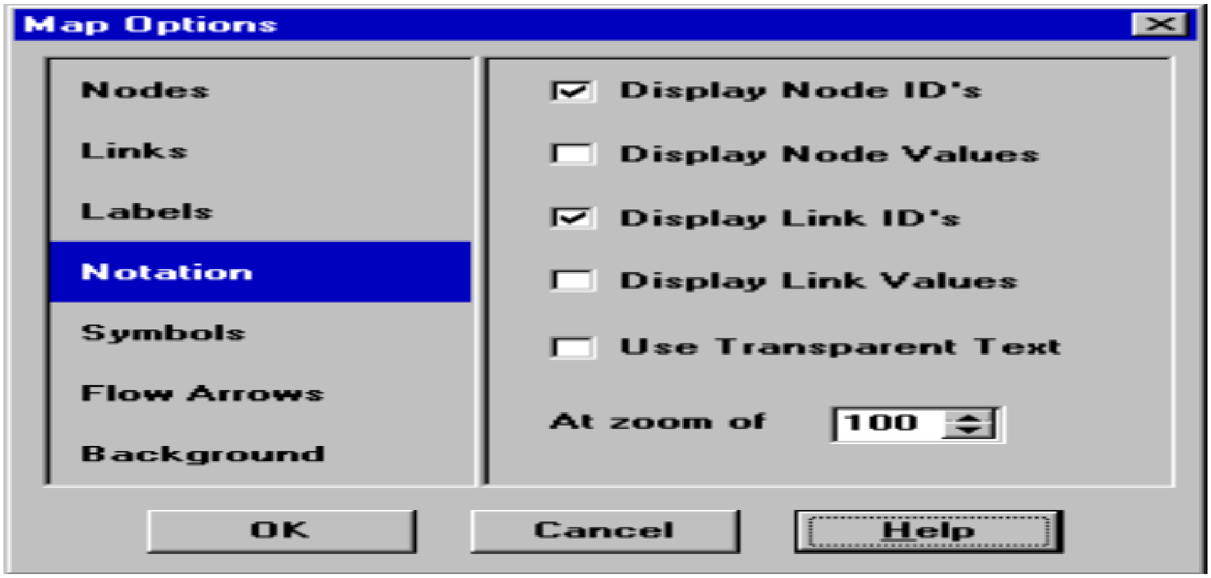
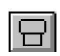
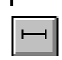


Figure 2.1:Map Options Dialog

2.3 Drawing Sokoto Water Distribution Network

We begin drawing the Sokoto network by making use of the mouse and the buttons contained on the map toolbar shown below. (If the toolbar is not visible then select view >> toolbars >> map).

First we add the three (3) source nodes / reservoirs, by the reservoir button,  then click the mouse on the map at the location of the reservoir (somewhere to the left of the map). Next we add the junction nodes. Click the junction button  and then click on the map at the diverse locations within the town, including the ten (10) zero demand nodes adjacent to the pumps. Finally, we add the six (6) Sokoto township tanks (4 underground and 2 overhead) by clicking the tank button  and clicking the map where the tank is located. Next we add the pipes. Beginning with the 6 (six) main pipes 1, 2, 3, 4, 5 and 6 connecting four (4) underground nodes. First click the pipe button  on the toolbar. Then click the mouse on the source node on the map and then on the tank node. Note how an outline of the pipe is drawn as you move the mouse from one node to the other. Repeat this procedure for all the pipes ; 1,2,3,4,5,6,19,20,28,38 are curved. To draw them, click the mouse first on the node before the curve. Then as you move the mouse towards the node preceding the curve, then, click at those points where a change of direction is needed to maintain the desired shape. Complete the process by clicking on the node preceding the curve.

Finally we add the ten (10) pumps, adjoining all the tanks / reservoirs; click the pump button, click on nodes in between where the pump will be located. For example, click on node 1 and then on node 2. Next label the reservoir, pump and tank. Select the text button  on the map toolbar and click somewhere close to the source node (reservoir node 1). An edit box appeared, type in the word Source and then hit the enter key, and click next to continue until both hydraulic and water quality modeling existing in the study area is achieved.

The labels can be repositioned in similar fashion as designed. To reshape the curved pipe:

1. First click on any of the pipes; select it and then click the  button on the map toolbar to put the map into vertex selection mode.
2. Vertex point on the pipe was selected by clicking on it and then drag it to a new position with the left mouse button held down.
3. If required, vertices can be added or deleted from the pipe by right clicking the mouse and selecting the appropriate option from the pop up menu that appears.
4. When finished, click  to return to object selection mode.

2.4 EPANET Object Properties Setting for Sokoto Water Distribution Network

As objects are added to a project they are assigned a default set of properties. To change the value of a specific property for an object one must select the object into the property editor

(Figure 2.2). There are several different ways to do this. If the editor is already visible then you can simply click on the object or select it from the data page of the browser. If the editor is not visible then you can make it appear by one of the following actions:

i. Double-click the object on the map.
ii. Right-click on the object and select propertiesfrom the pop-up menu that appears.
iii. Select the object from the data page of the browser window and then click the browser's edit button .Whenever the property editor has the focus you can press the F1 key to obtain fuller descriptions of the properties listed.

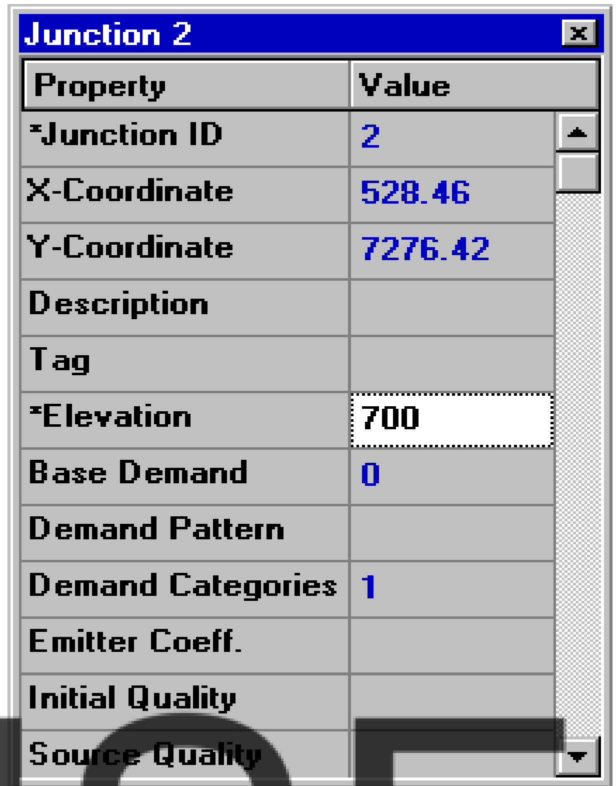


Figure 2.2: Property Editor

We begin by editing the selected Node 2 into the property editor as in figure 2.3. The elevation and demand for the node in the appropriate fields is entered. The up and downarrows and the mouse on the keyboard are move between fields. We need to only click on another object (node or link) to have its properties appear next in the property editor. (We could also press the page down or page up key to move to the next or previous object of the same type in the database.) Thus we can simply move from object to object and fill in elevation and demand for nodes, lengths, diameters, and roughness (C-factor) for links. For the four ground reservoirs/tanks we enter their diameters of 6.5m each and their elevations, for the two overhead tanks, we enter 282m and 292m put values for its initial and for maximum level, and 13m for tank diameter. For the pump, we assigned it a pump curve (head versus flow relationship). ID label 1 in the pump curve field was entered. Pump curve 1, was created, from the data page of the browser window, curves were selected from the dropdown list box and the Add button pressed . A new Curve 1 was created to the database and the curve editor dialog form appeared (see Figure 2.3). Pumps design flow of (600) and head (150) were entered in to the form, Epanet automatically creates a complete pump curve from this single point.

The curve's equation is shown along with its shape and OK was clicked to close the editor.

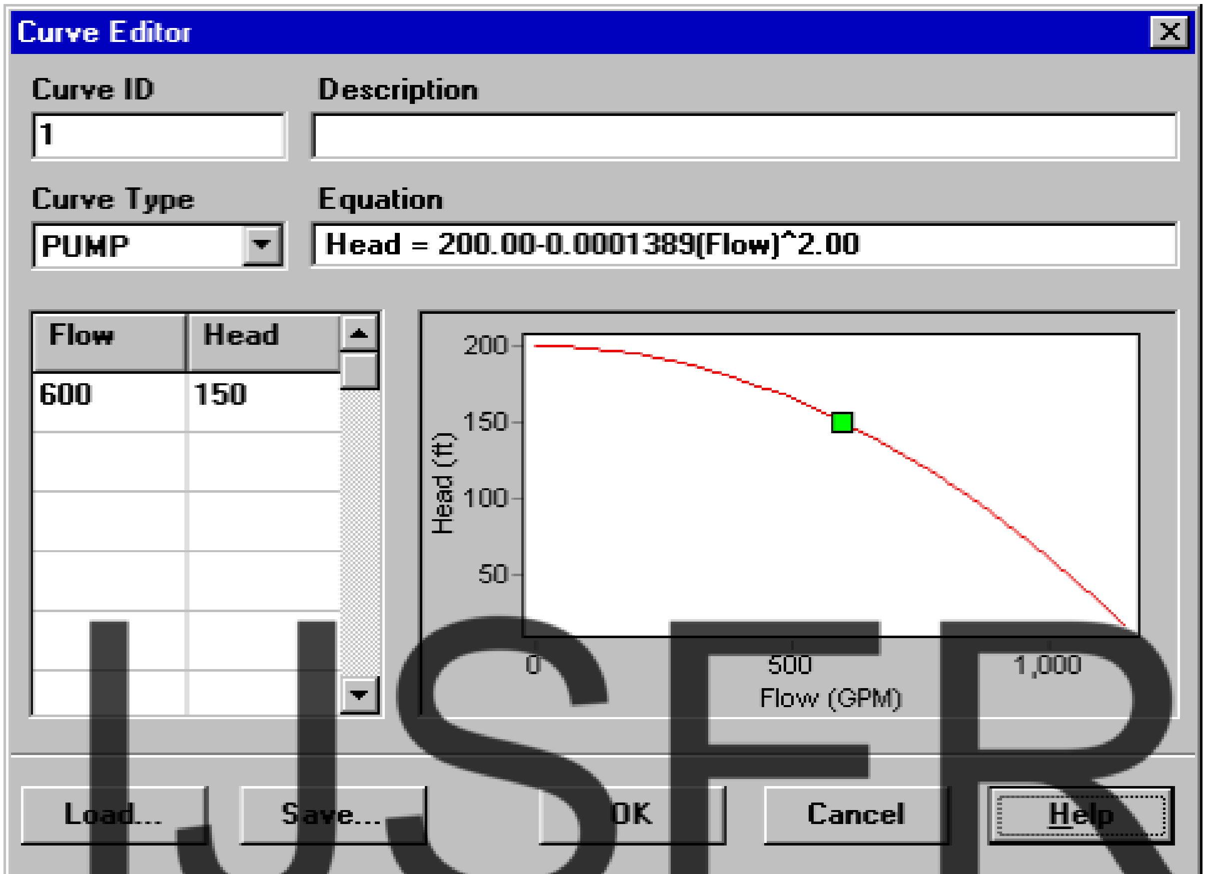


Figure 2.3 Curve Editor Dialog form

2.5 EPANET Saving and Opening for Network Project

Having completed the initial design of the network the work is been saved to a file. The procedure for saving is as follows

1. From the file menu the save As option was selected.
2. In the save As dialog that appears, a folder and file name was selected and the project saved. The file was named New Sokoto Water Distribution Network.net.
3. OK was clicked, and the project was saved to file. The project data was saved to the file, in a special binary format. If you wanted to save the network data to file as readable text, use the file >> export >> network command instead. To open the project at some later time, we would select the open command from the filemenu.

2.5.1 Running EPANET 2.0 Single Period Analysis

We now have enough information to run a single period (or snapshot) hydraulic analysis on the network. To run the analysis select project >> run analysisor click the run button on the standard toolbar. (If the toolbar is not visible select view >> toolbars >> standardfrom the menu bar). If the run was unsuccessful then a Status Report window will appear indicating what the problem was. If it ran successfully you can view the computed results in a variety of ways. Try some of the following:

Select node pressure from the browser's map page and observe how pressure values at the nodes become color-coded. To view the legend for the color-coding, select view >> legends >> node (or right click on an empty portion of the map and select node legend from the popup menu).

To change the legend intervals and colors, right click on the legend to make the legend editor appear. Bring up the property editor (double-click on any node or link) and note how the computed results are displayed at the end of the property list. Create a tabular listing of results by selecting report >> table (or by clicking the table button on the standard toolbar). Figure 3.4 displays such a table for the link results for a typical example. Note that flows with negative signs means that the flow is in the opposite direction to the direction in which the pipe was drawn initially.

Network Table - Links

Link ID	Flow GPM	Velocity fps	Headloss ft/Kft	Status
Pipe 1	617.42	1.29	0.80	Open
Pipe 2	382.51	1.09	0.69	Open
Pipe 3	159.91	1.02	1.00	Open
Pipe 4	29.34	0.19	0.04	Open
Pipe 5	-90.09	0.57	0.34	Open
Pipe 6	292.42	1.19	1.03	Open
Pipe 7	55.58	0.63	0.57	Open
Pipe 8	-44.42	0.50	0.38	Open

Figure 2.4: EPANET Link Results

2.5.2 Running an EPANET 2.0 Extended Period Analysis

To make the network more realistic for analyzing an extended period of operation, we create a time pattern that makes demands at the nodes vary in a periodic way over the course of the day. For the project we use a pattern time step of 1hours thus making demands change after an hour and 24 different times of the day. Options-times pattern time step was set from the data browser, clicking the browser's edit button to make the property editor appear if, not already visible and 6 for the value of the pattern time step were entered as shown in figure 2.5. While we have the time options available we can also set the duration for which we want the extended period to run. We use a 30days period of time (720 hours was entered for the duration property).

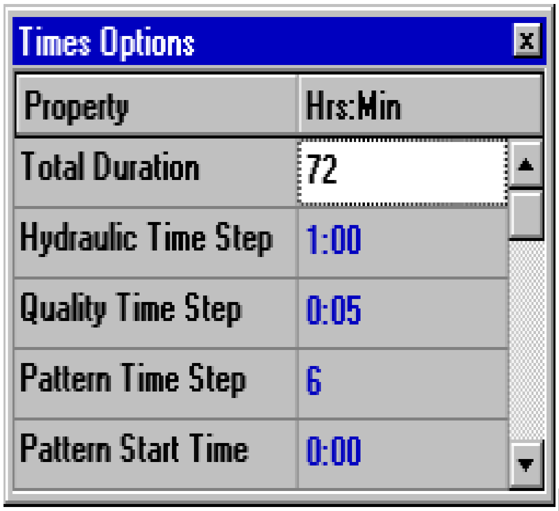


Figure 2.5:Times Options

2.5.3 Running EPANET 2.0 Water Quality Analysis

Next is to analysis the network water quality. The simplest case would be tracking the growth in water age throughout the network over time. To make this analysis we only have to select age for the parameter property in the quality options (options-quality from the data page of the browser was selected, and then the browser's edit button was clicked to make the property editor appear).

Finally we show how to simulate the transport and decay of chlorine through the network. The following changes were made to the database:

1. Options-Quality was selected to enable edit from the data browser. In the property editor's parameter field, the word chlorine was typed.

2. Switch to options-reactions in the browser. For global bulk coefficient enter a value of -1.0., this reflects the rate at which chlorine will decay due to reactions in the bulk flow over time. This rate will apply to all pipes in the network. You could edit this value for individual pipes if you needed to.

3. Click on the reservoir node and set its initial quality to 1.0. This will be the concentration of chlorine that continuously enters the network. (The initial quality in the tank was reset to 0), now run the project. Use the time controls on the map browser to see how chlorine levels change by location and time throughout the simulation. Reaction report was created for the run by selecting report >> reactionfrom the main menu, the report should look like Figure 3.6, It shows on average, how much chlorine loss occurs in the pipes as opposed to the tank. The term “bulk” refers to reactions occurring in the bulk fluid while “wall” refers to reactions with material on the pipe wall.

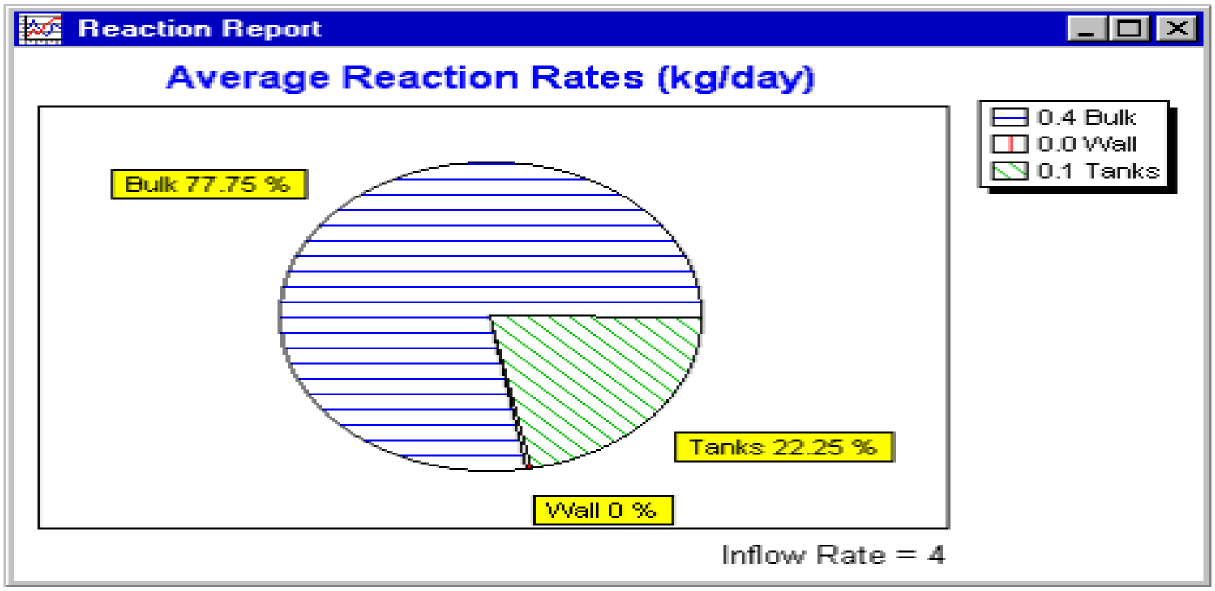


Figure 2.6:Typical Reaction Report

2.6 EPANET Toolkit Usages

A typical usage of the toolkit functions, to analyze a distribution system might look as follows:

1. Use the ENopen function to open the toolkit system, along with an Epanet Input file.
2. Use the ENsetxxx series of functions to change selected system characteristics.
3. Run a full hydraulic simulation using the ENsolveH function (which automatically saves results to a hydraulics file) or use the ENopenH - ENinitH - ENrunH - ENnextH - ENcloseH series of functions to step through a hydraulic simulation, accessing results along the way with the ENgetxxx series of functions.
4. Run a full water quality simulation using ENsolveQ (which automatically saves hydraulic and water quality results to an output file) or use the ENopenQ - ENinitQ - ENrunQ - ENnextQ (or ENstepQ) - ENcloseQ series of functions to step through a water quality simulation, accessing results along the way with the ENgetxxx series of functions.
5. Return to step 2 to run additional analyses or use the ENreport function to write a formatted report to the report file.
6. Call the ENclose function to close all files and release system memory.

2.7 Procedure for Designing EPANET 2.0 Sokoto Water Distribution Network Ideal model of Sokoto water distribution network was determined after series of attempted adjustments, tinkering and tweaking of the hydraulic simulation components and the water quality simulation variables for proper calibration and validation Calibration of Epanet 2.0 Sokoto predicted results and the real values measured at the locations within the study area was properly achieved and realized, using the standard methods of calibration through Epanet 2.0 Software, by registering the calibration data at ten (10) most critical points in the network of study, six (6) locations in zone A and four(4) locations in zone B to be calibrated against the predicted values in Epanet 2.0; the network sample locations are 31, 9, 8, 34, 24, 20, 22, 29, 19 and 16. During the calibration process and for effective correlation to be achieved, the wall decay and bulk decay coefficients of the following critical pipes were further changed; pipe 15, 11, 23, 39, 32, 28, 35 and 36 for wall decay and pipes 15, 23, 35 and 36 for bulk decays. Validation of the calibrated Sokoto Epanet 2.0 predicted results and the real values measured at the locations within the study area was accomplished, using the standard methods of validation through Epanet 2.0 software, by registering the remaining measured chlorine values in the metropolis with the exception of the tanks and reservoir values that are fixed values. The network sample locations are 18, 21, 15, 17, 25, 23, 28, 30, 13, 27, 11, 12 and 14. During the validation process few of the values are not properly read as in Figure 3.2.2, due to perceived errors in the location measured values.

3.0 RESULTS AND DISCUSSIONS(

3.1 Sokoto Water Distribution Network Improved Model

The well calibrated and validated, ideal model of Sokoto water distribution network, originated after series of attempted adjustments, tinkering and tweaking of the hydraulic simulation components and the water quality simulation variables. The ideal Sokoto Water Distribution Network is presented in figure 3.0

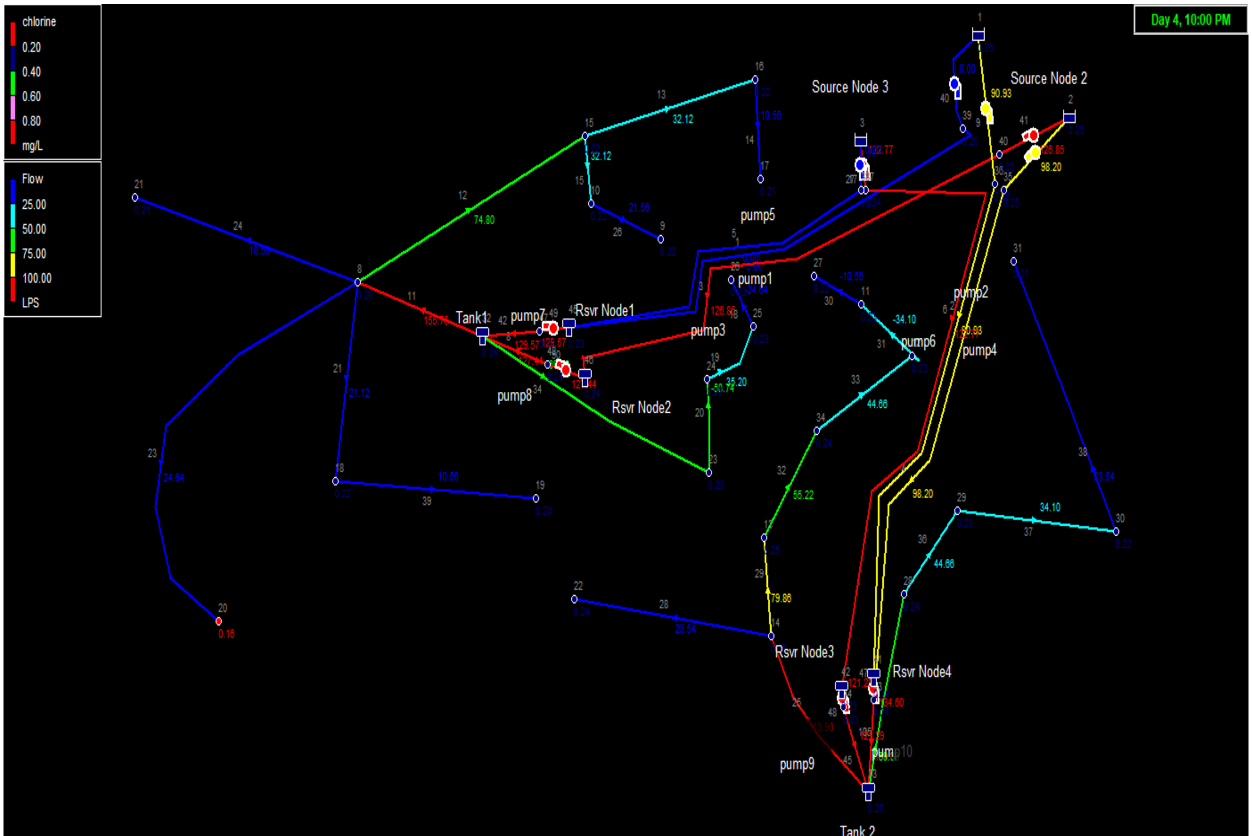


Figure 3.0: Sokoto Epanet 2.0 Water Supply and Distribution Network Model

3.2 Sokoto Water Distribution Network Ideal Model Results

The ideal water quality simulation result, pristinely and properly designed for Sokoto water distribution network to depict the actual situation in the network area is hereby presented; to portray the improvement in the new model.

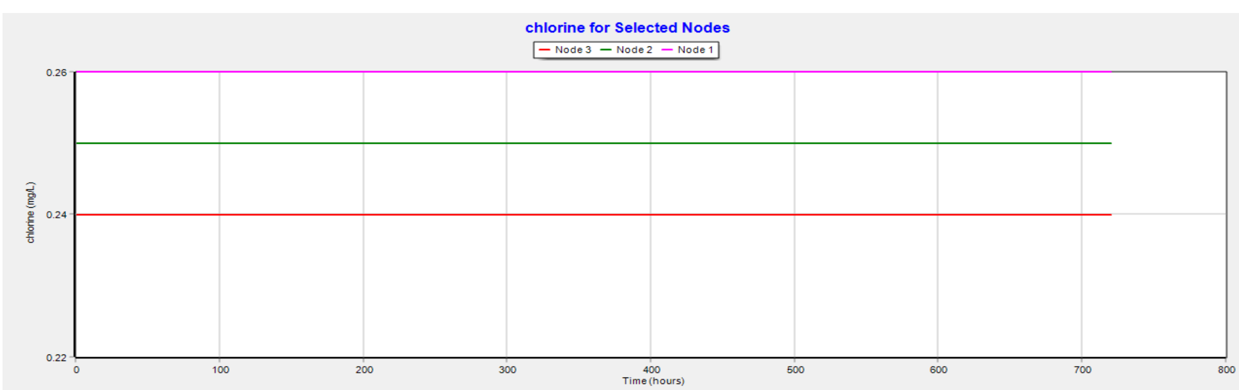


Figure 3.1: Simulation graph depicting Chlorine conc. at source nodes 1, 2, and 3

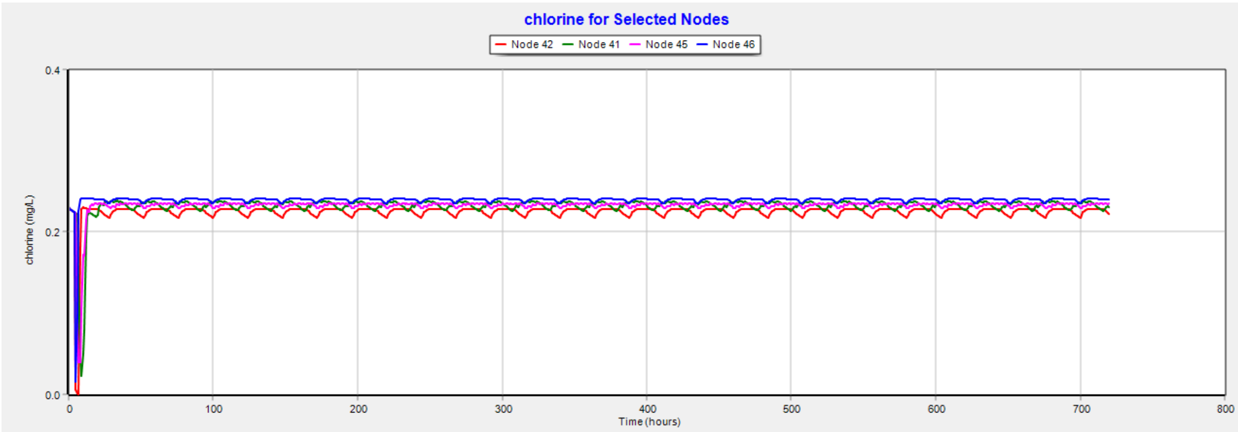


Figure 3.2: Simulation graph depicting Chlorine at reservoir tank 42, 41, 45 and 46

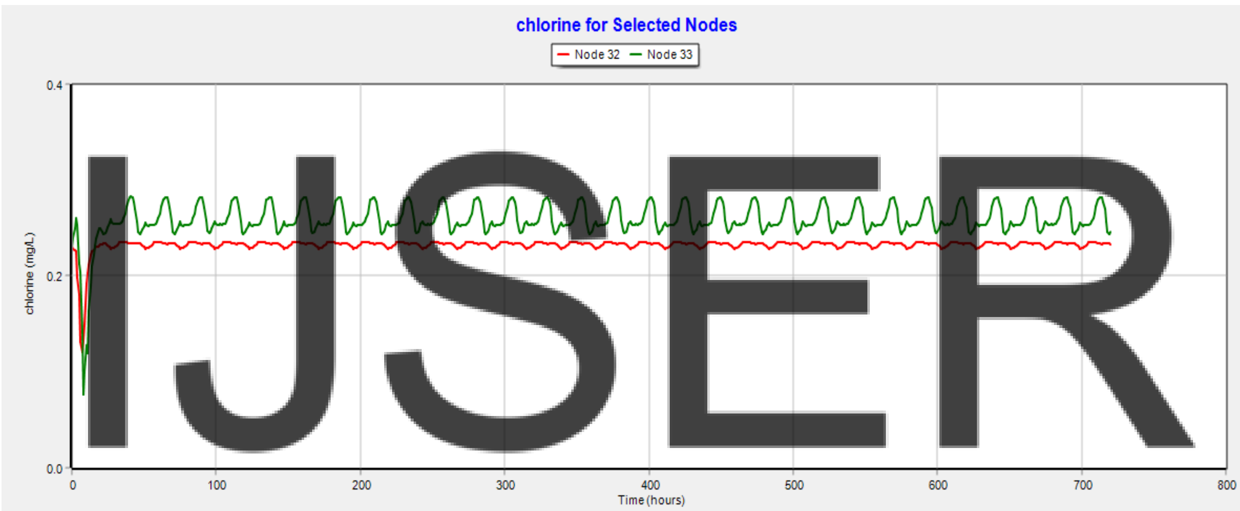


Figure 3.3: Simulation graph depicting Chlorine Conc. at overhead tank 32 and 33

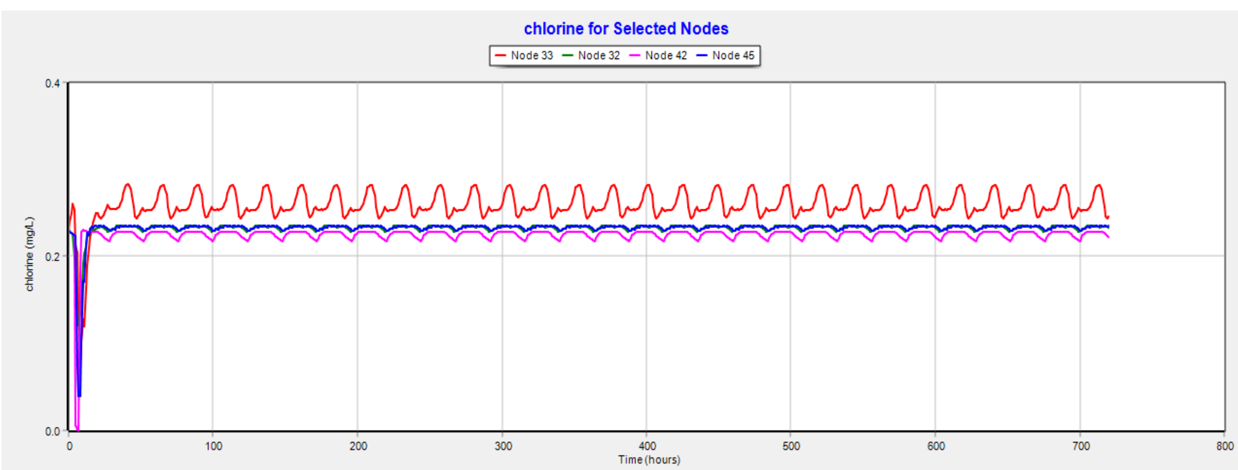


Figure 3.4: Simulation graph depicting Chlorine at ground and overhead tank nodes 33, 32, 42 and 45.

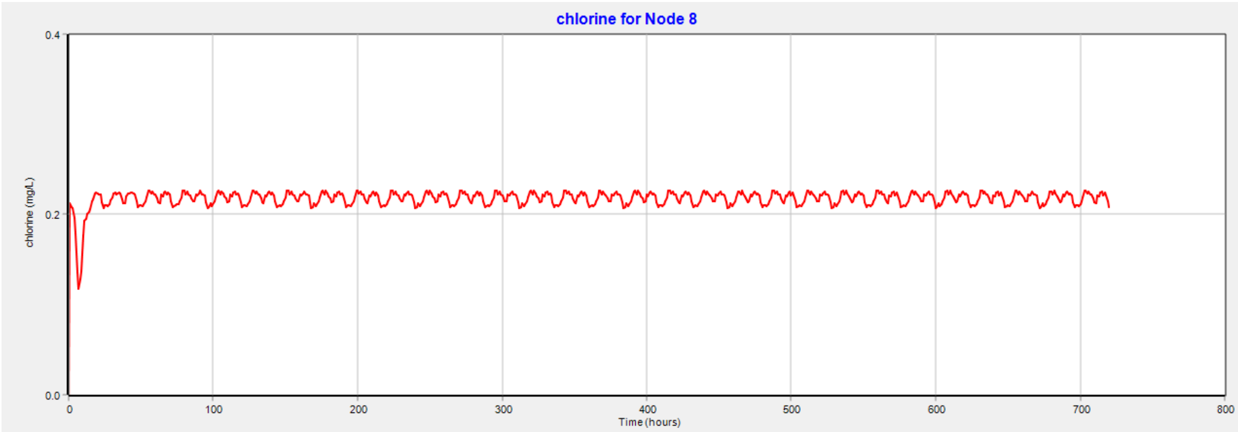


Figure 3.5: Simulation graph depicting Chlorine Conc. at junction node 19

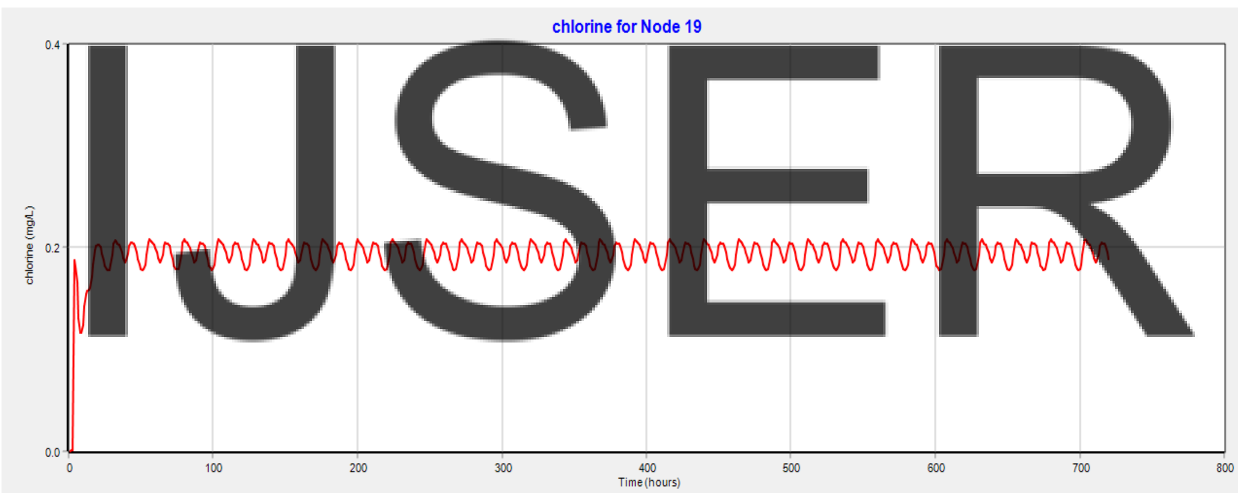


Figure 3.6: Simulation graph depicting Chlorine Conc. at junction node 19

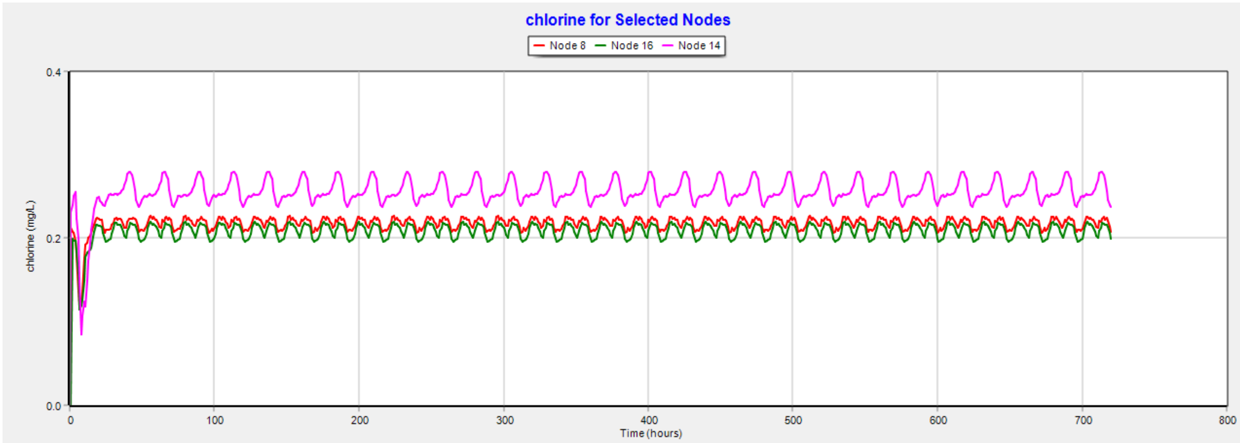


Figure 3.7: Simulation graph depicting Chlorine Conc. at junction node 8, 16 and 14

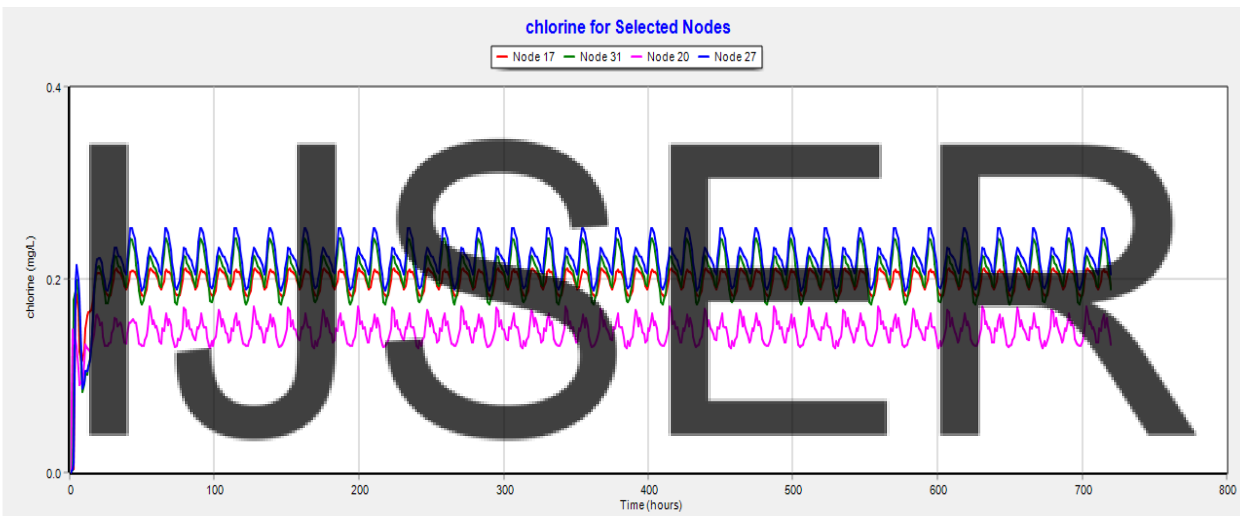


Figure 3.8: Simulation graph depicting Chlorine Conc. at junction 17, 31, 20 and 27.

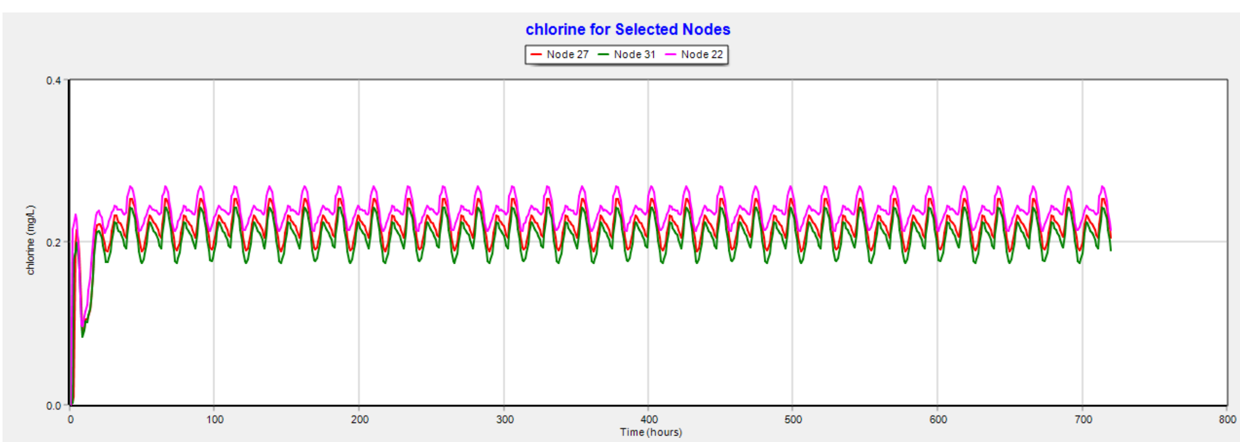


Figure 3.9: Simulation graph depicting Chlorine Conc. at junction node 27, 31 and 22.

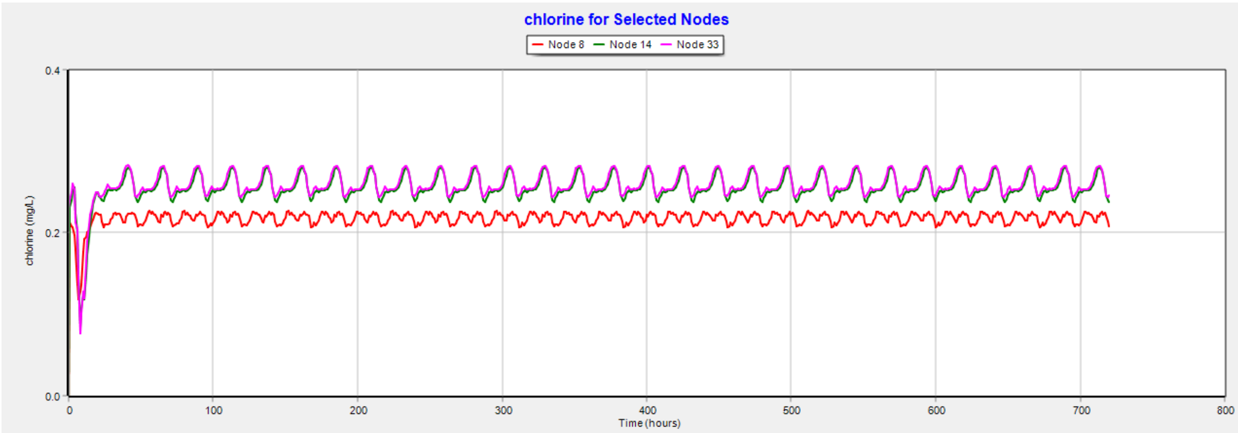


Figure 3.10: Simulation graph depicting Chlorine Conc. at junction node 8, 14 and 33.

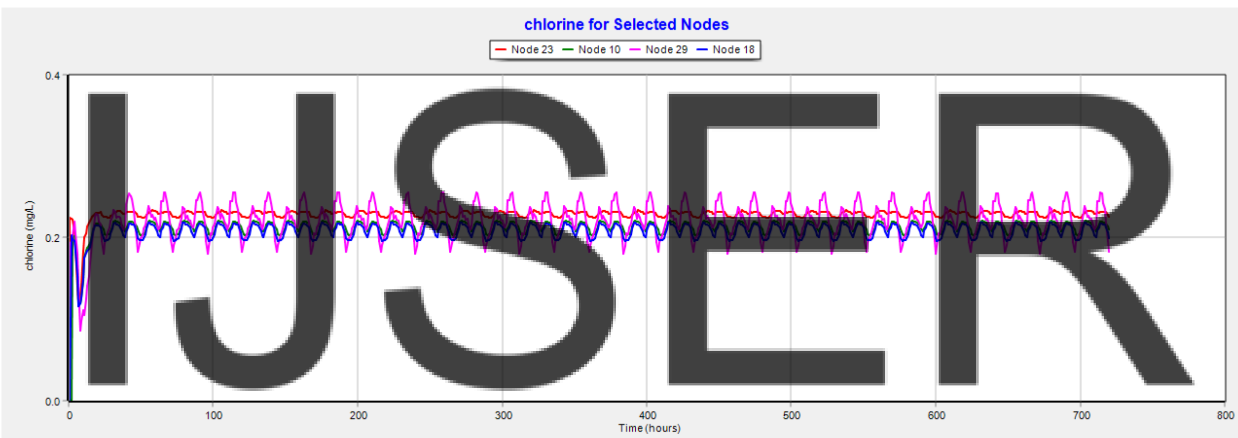


Figure 3.10.1: Simulation graph depicting Chlorine Conc. at junction 23, 10, 29 and 18.

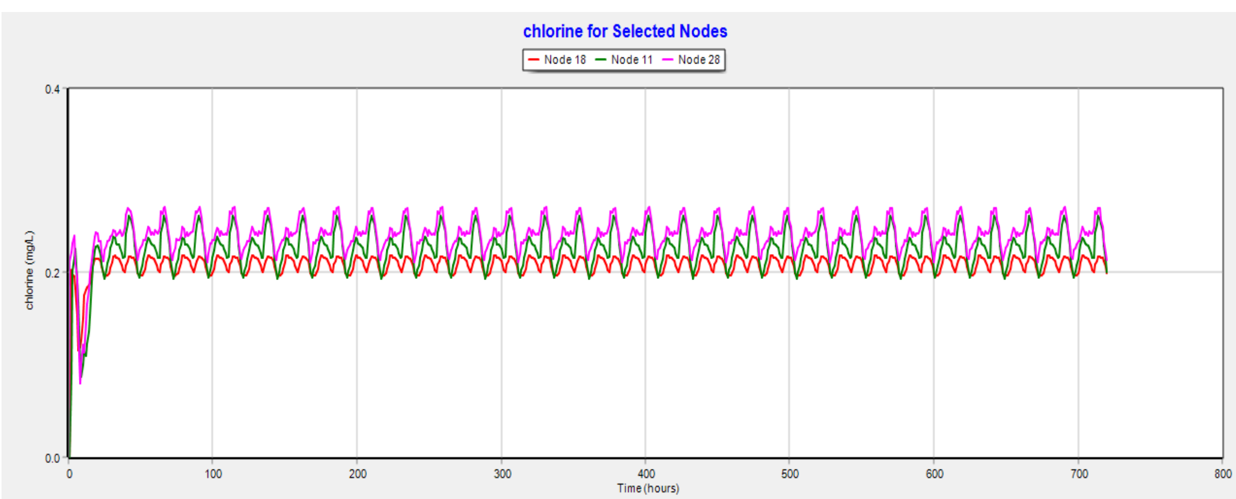


Figure 3.10.2: Simulation graph depicting Chlorine Conc. at junction node 18, 11 and 28.

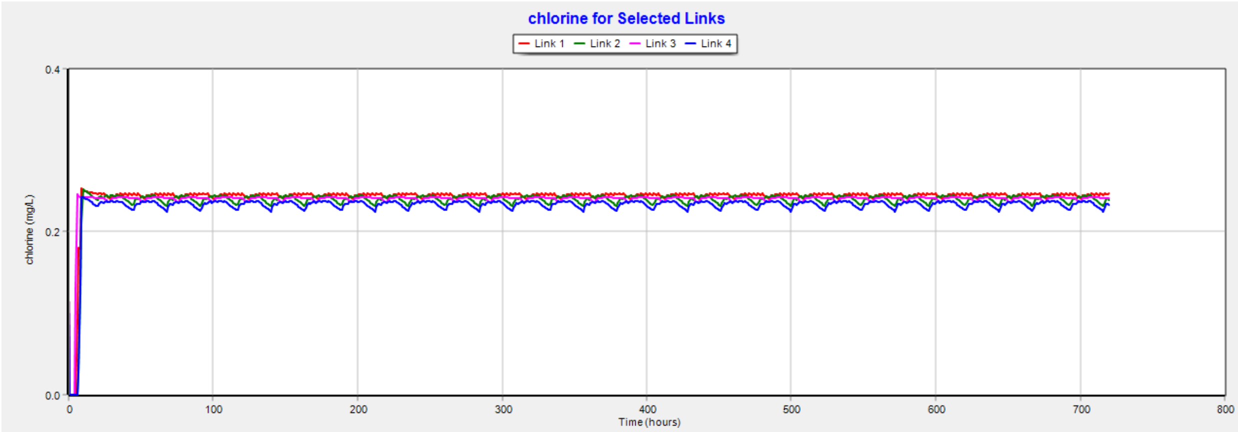


Figure 3.10.3: Simulation graph depicting Chlorine Conc. at pipe links 1, 2, 3 and 4

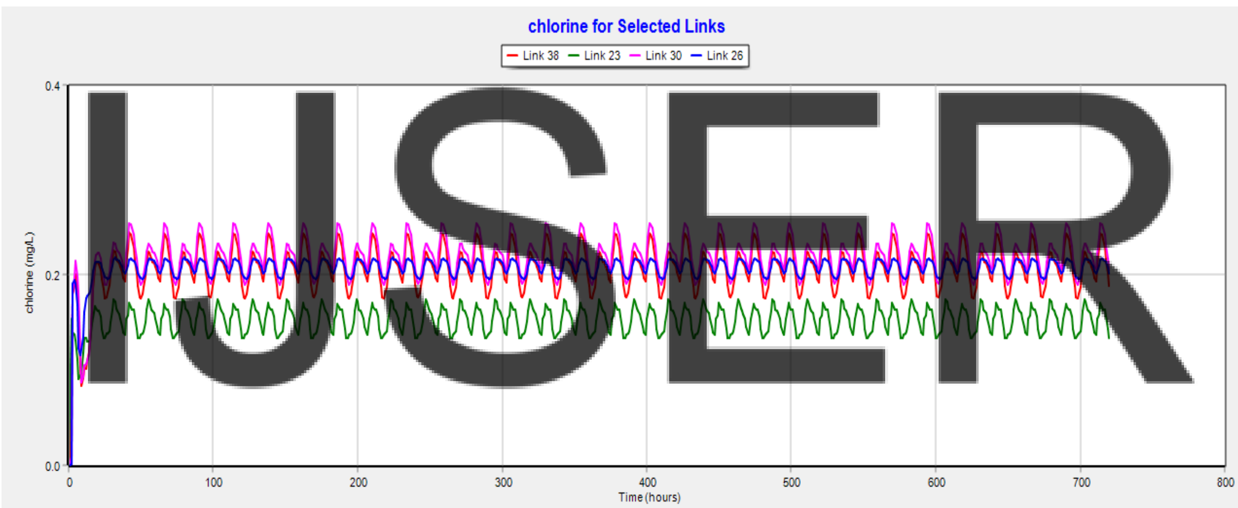


Figure 3.10.4: Simulation graph depicting Chlorine Conc. at pipe links 38, 23, 30 and 26

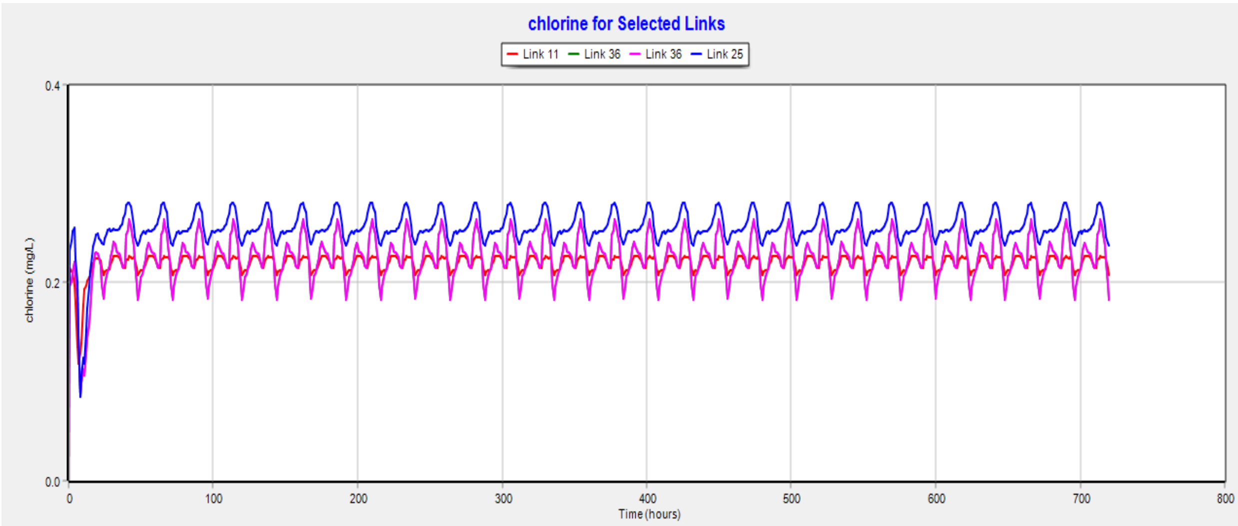


Figure 3.10.5: Simulation graph depicting Chlorine Conc. at pipe links 11, 36, 35 and 25

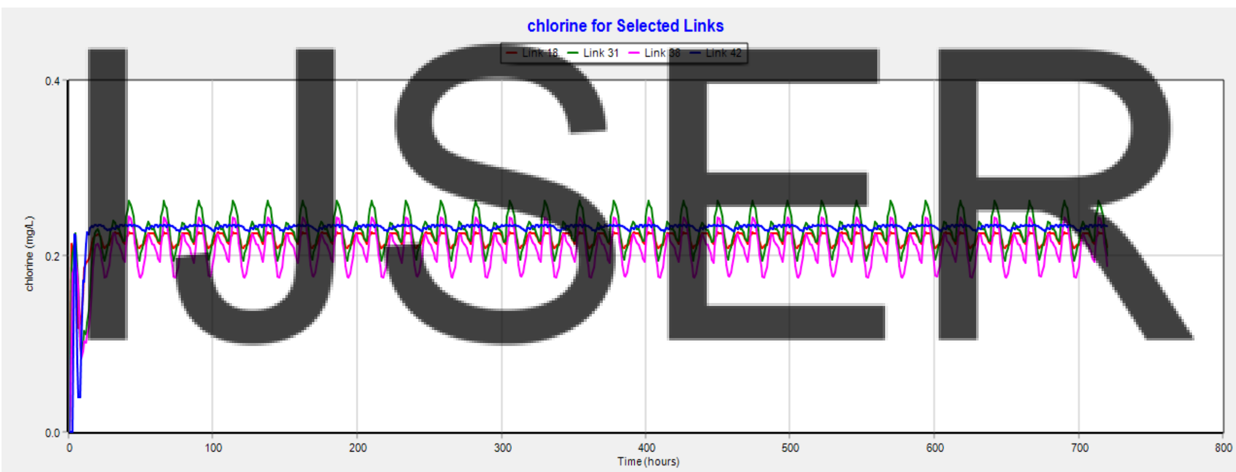


Figure 3.10.6: Simulation graph depicting Chlorine Conc. at pipe links 18, 31, 38 and 42.

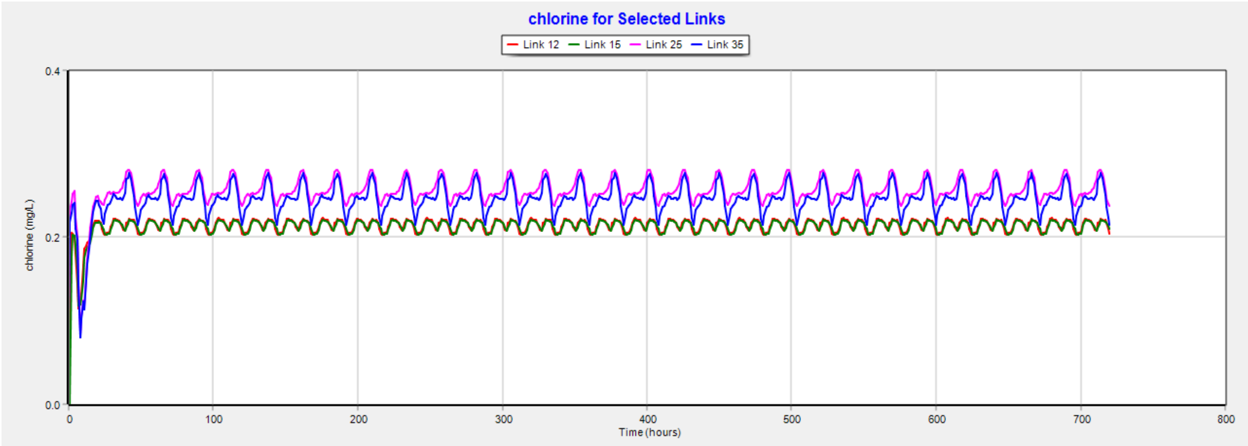


Figure 3.10.7: Simulation graph depicting Chlorine Conc. at pipe links 12, 15, 25 and 35.

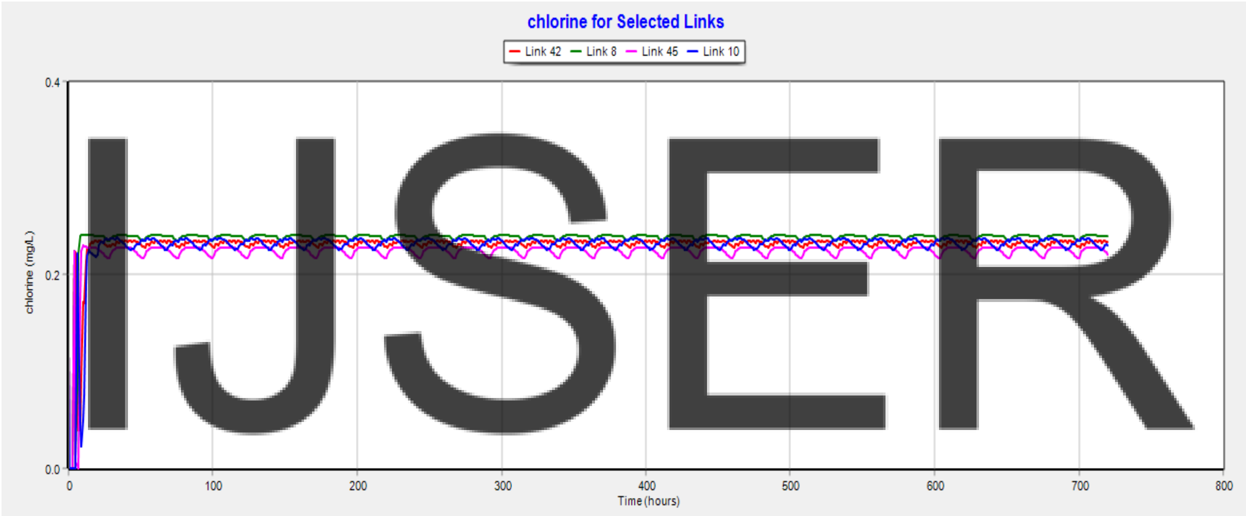


Figure 3.10.8: Simulation graph depicting Chlorine Conc. at pipe links 42, 8, 45 and 10.

Figure 3,10.9: Simulation graph depicting Chlorine Conc. at pipe links 40, 9, 17 and 27.

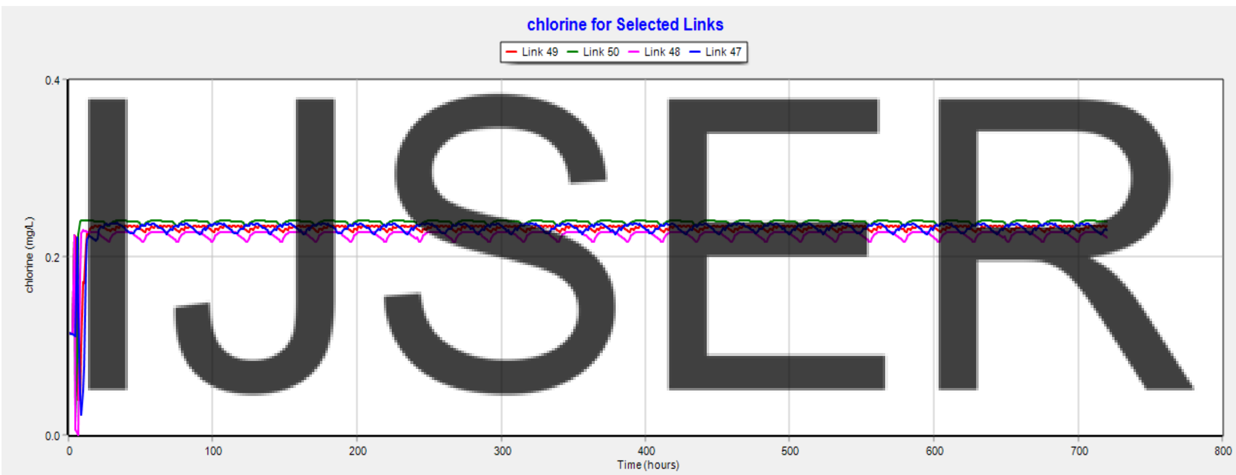


Figure 3.11: Simulation graph depicting Chlorine Conc. at pipe links 49, 50, 48 and 47

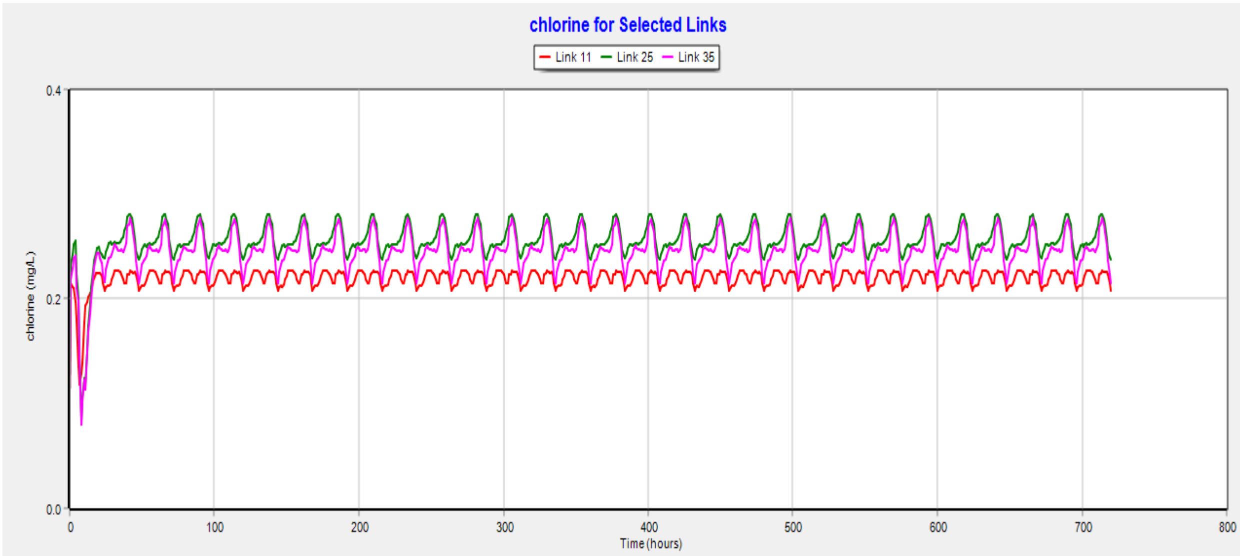


Figure 3.11.1: Simulation graph depicting Chlorine Conc. at pipe links 11, 25, and 35

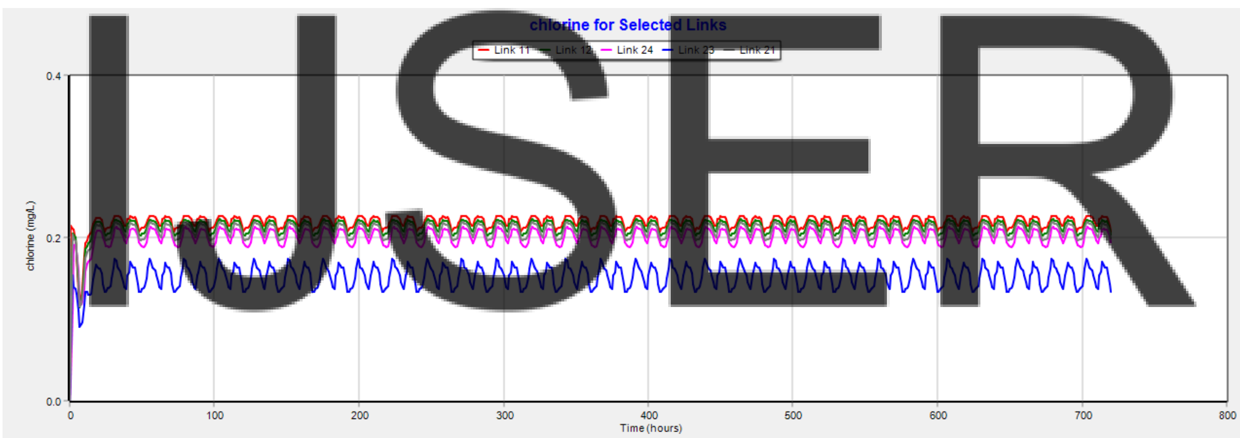


Figure 3.11.2: Simulation graph depicting Chlorine at pipe links 11, 12, 24 , 23 and 21.

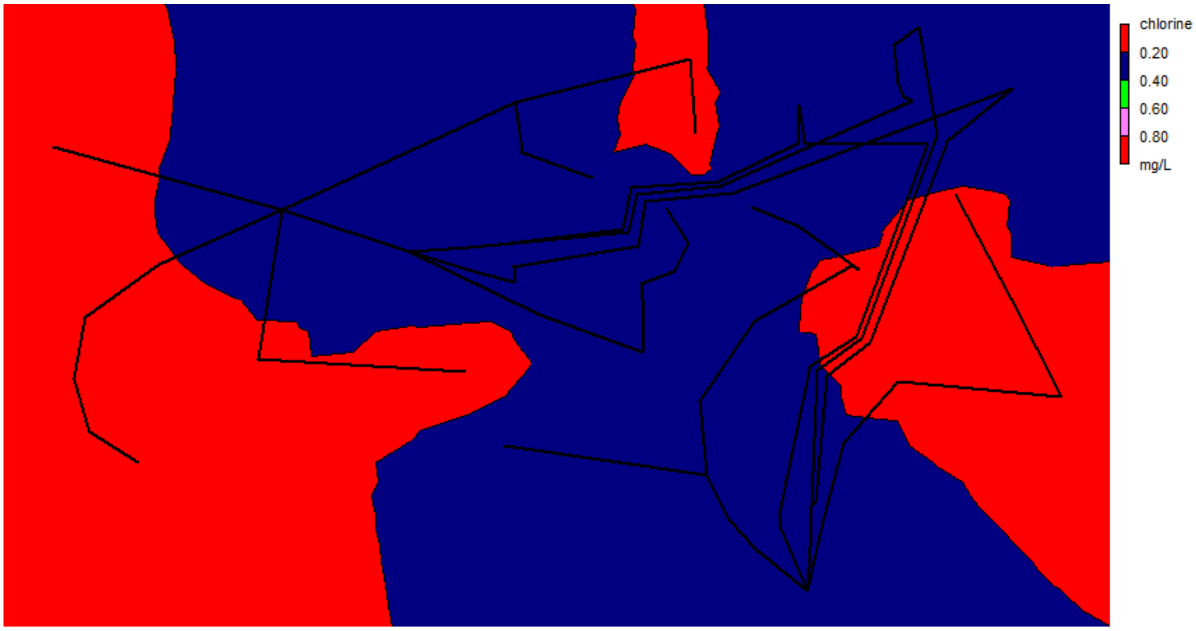


Figure 3.11.3.: Contour Distribution of Chlorine in the Network

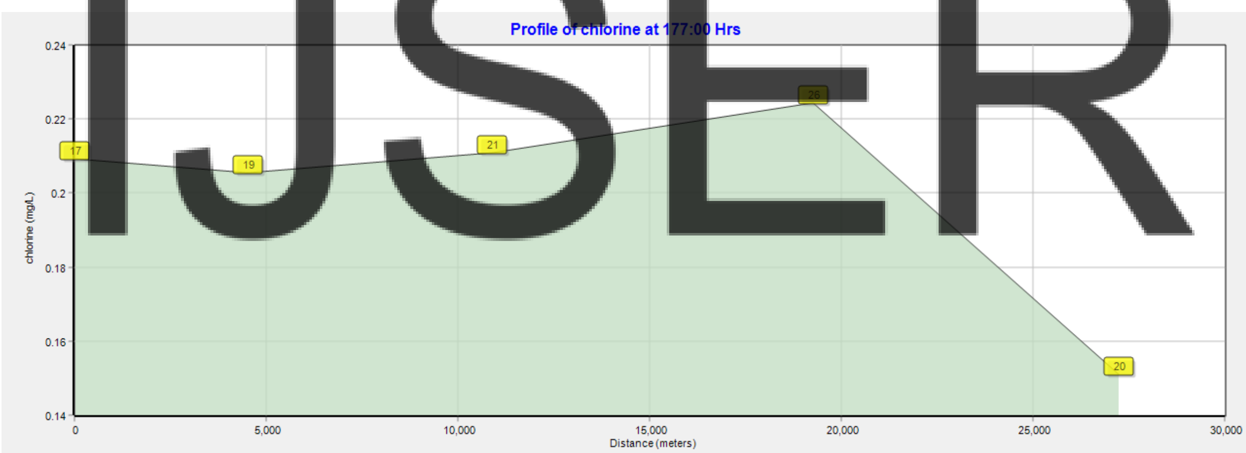


Figure 3.11.4: Simulation profile graph depict chlorine at junction 17, 19, 21, 26 and 20

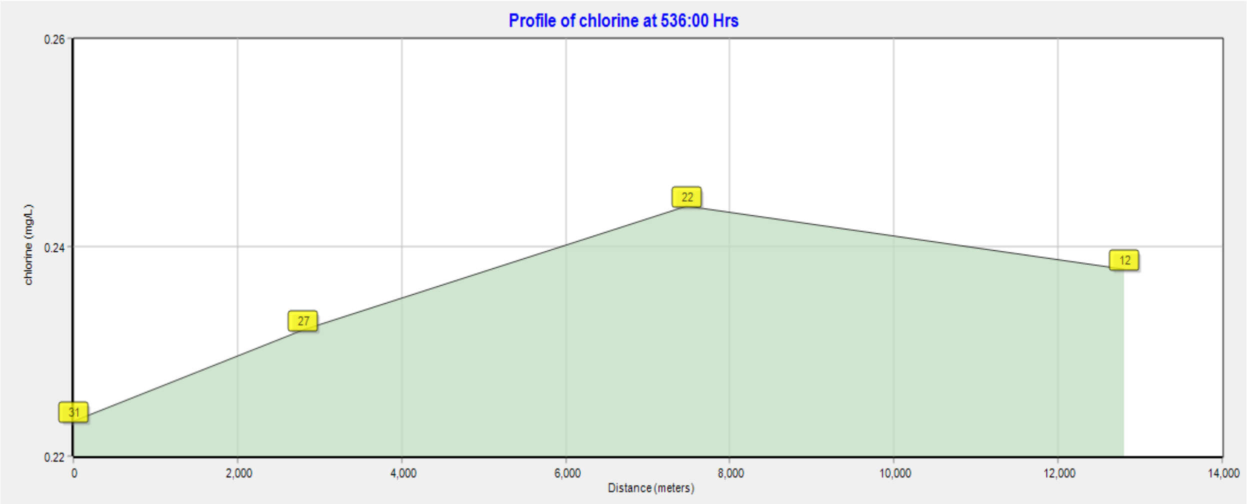


Figure 3.11.5: Simulation profile graph depicting chlorine at junction 31, 27, 22 and 12.

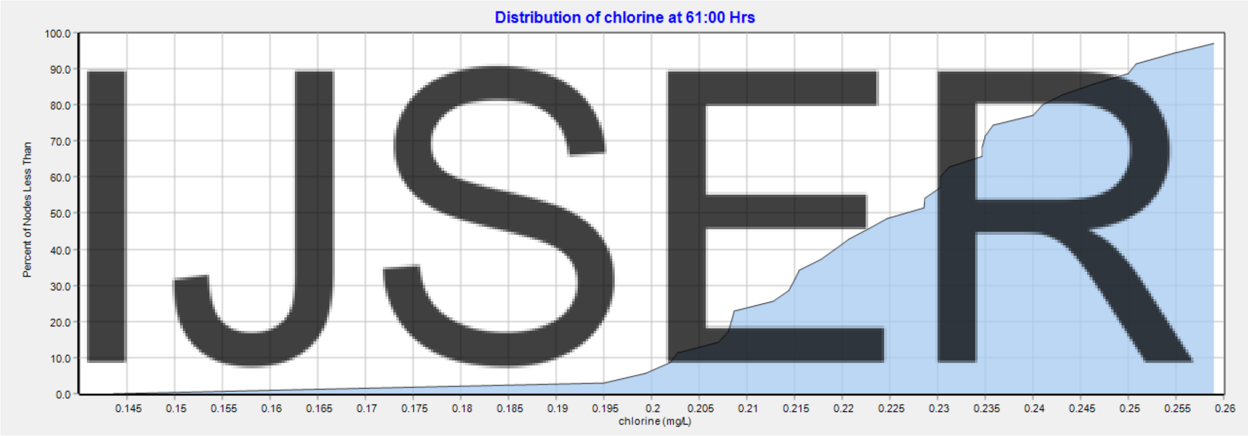


Figure 3.11.6: Chlorine Frequency Distribution network graph at 61:00 Hrs

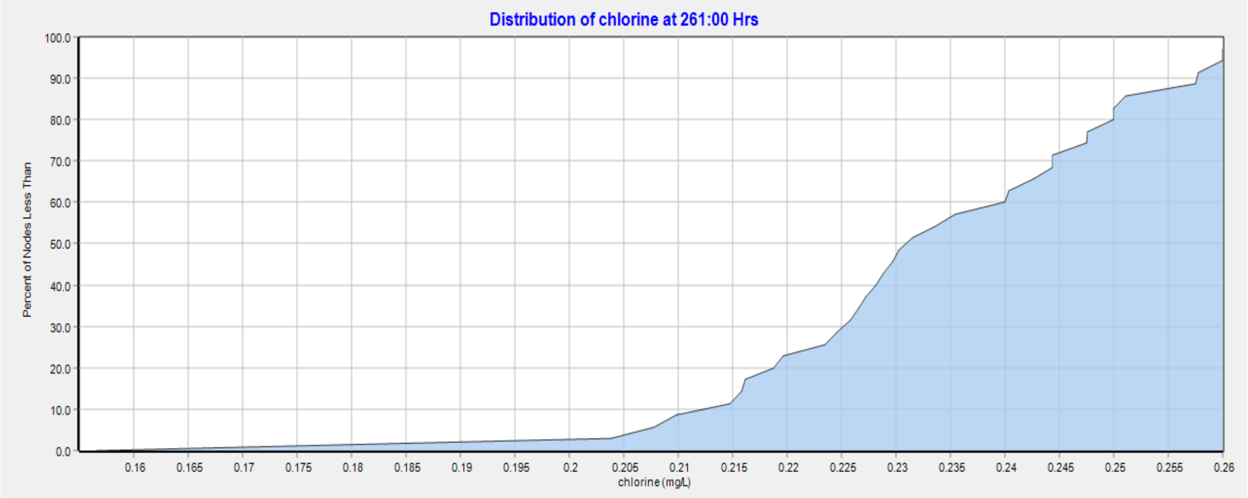


Figure 3.11.7: Chlorine Frequency Distribution network graph at 261:00 hrs

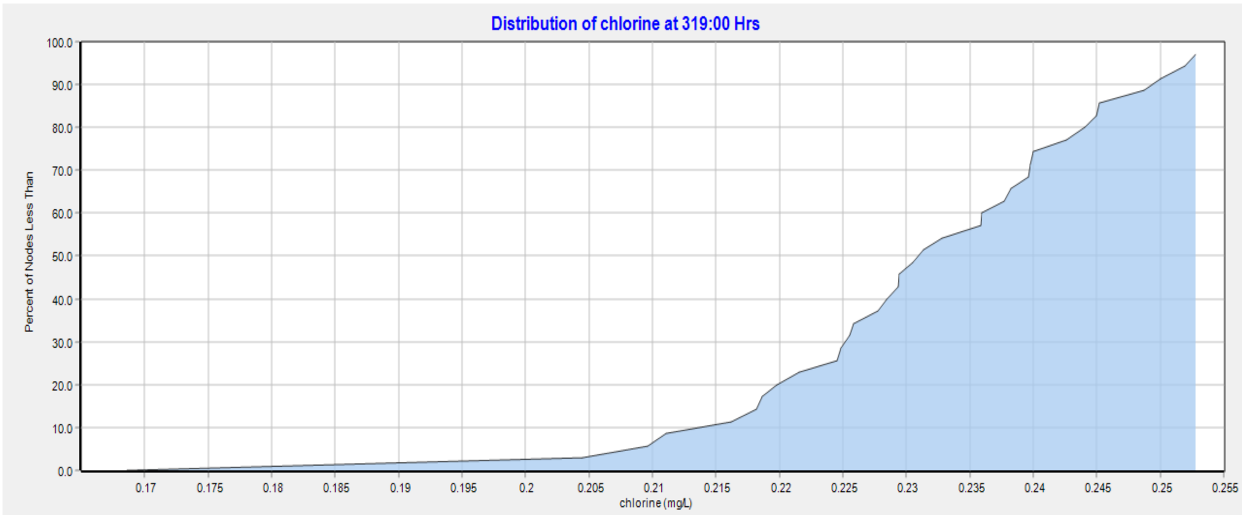


Figure 3.11.8: Chlorine Frequency Distribution network graph at 319:00 Hrs

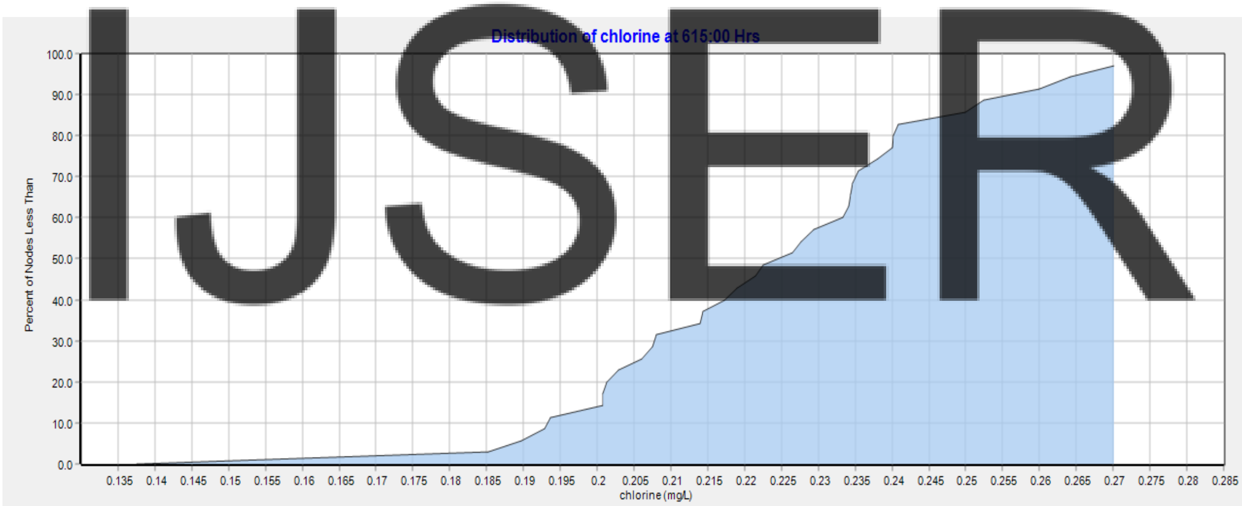


Figure 3.11.9: Chlorine Frequency Distribution network graph at 615:00 Hrs

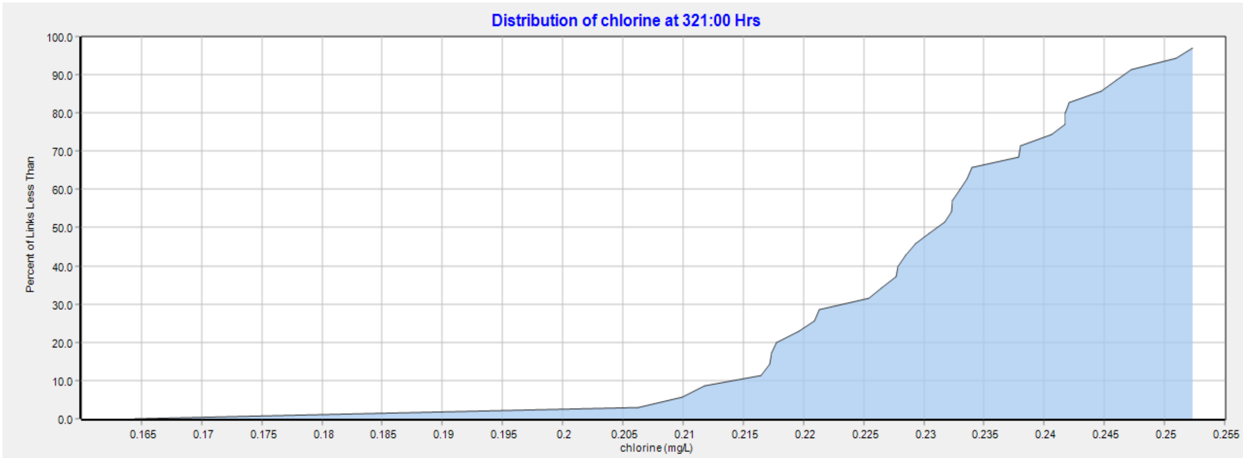


Figure 3.12: Chlorine Frequency Distribution network graph at 321:00 Hrs

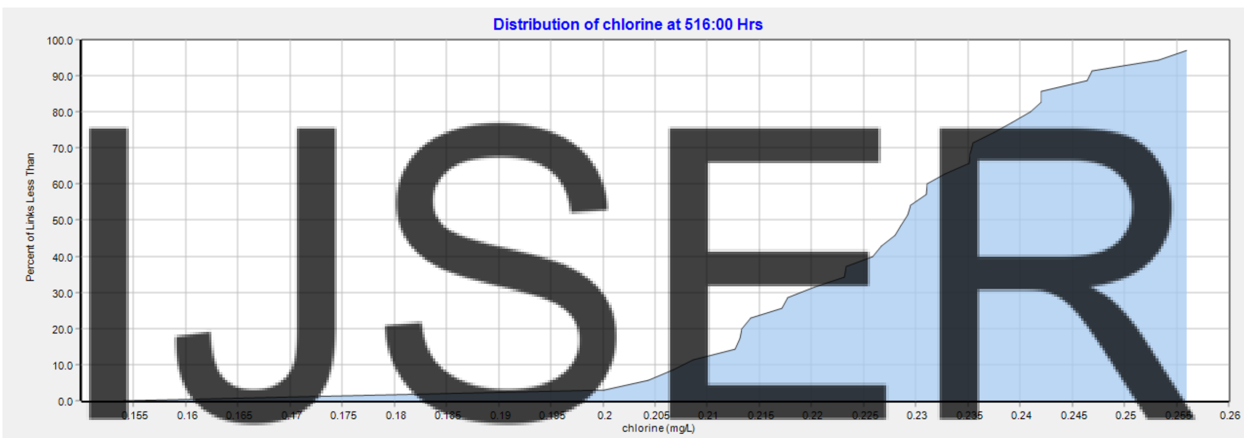


Figure 3.12.1: Chlorine Frequency Distribution Network Graph at 516:00 Hrs

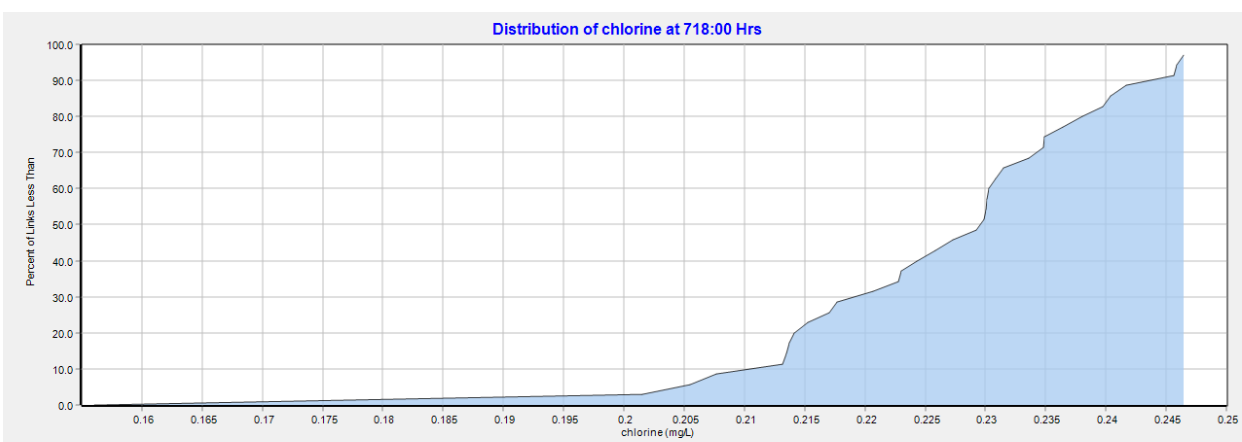


Figure 3.12.2: Chlorine Frequency Distribution Network Graph at 718:00 Hrs

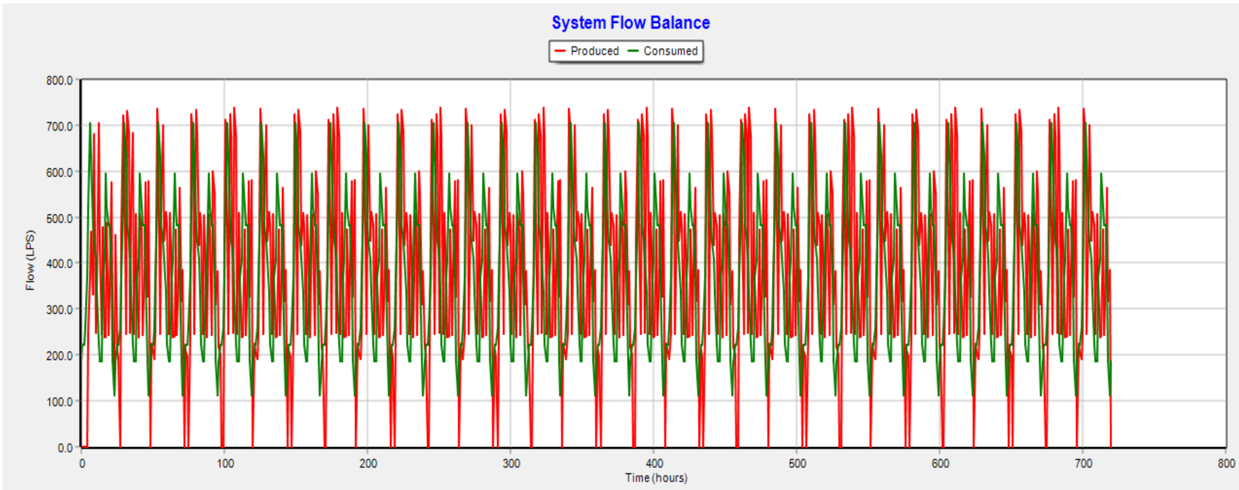


Figure 3.12.3: Simulation graph depicting System Flow Balance for the quantity produced and consumed

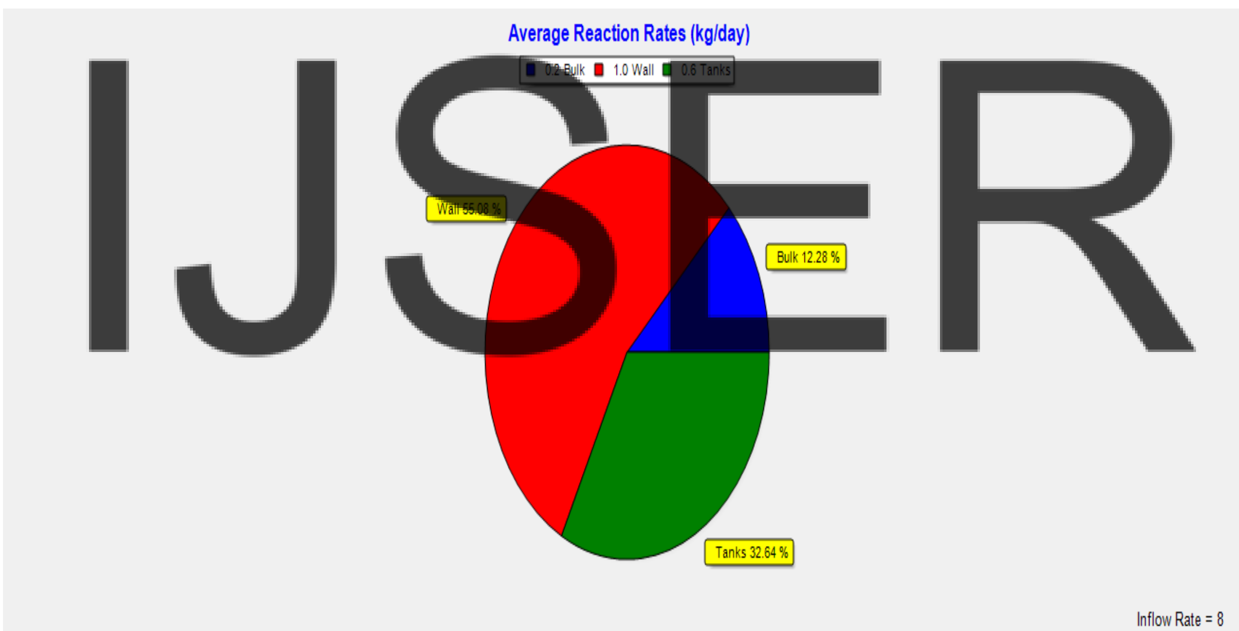


Figure 3.12.4: Simulation pie chart depicting Average Reaction Rates at bulk, wall and tanks (Kg/day).

3.2.1 Pump Energy Properties for Sokoto Water Distribution Network

When selecting pumps, static suction lift and static suction head (h_s) should be properly chosen for best performance. *Static suction lift*: is the vertical distance from the center line of the pump to the free surface level from where the liquid is to be lifted. *Static* *suction head*: is the distance from the center line of the pump to the free surface level where the liquid is to be delivered and the *Static discharge head* (h_d): is the distance between the center line of the pump to the free surface the liquid is delivered. The standard principle and rules regarding pumps selection in a water distribution network was adopted and the following figures represent the characteristics of the network pumps.

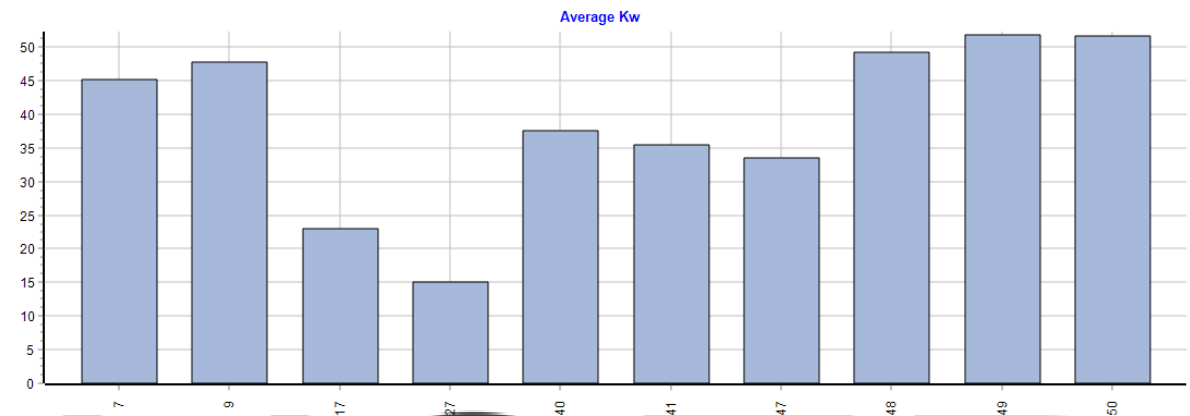


Figure 3.12.5: Histogram depicting Average Kilowatt (KW) for the Pump Lin

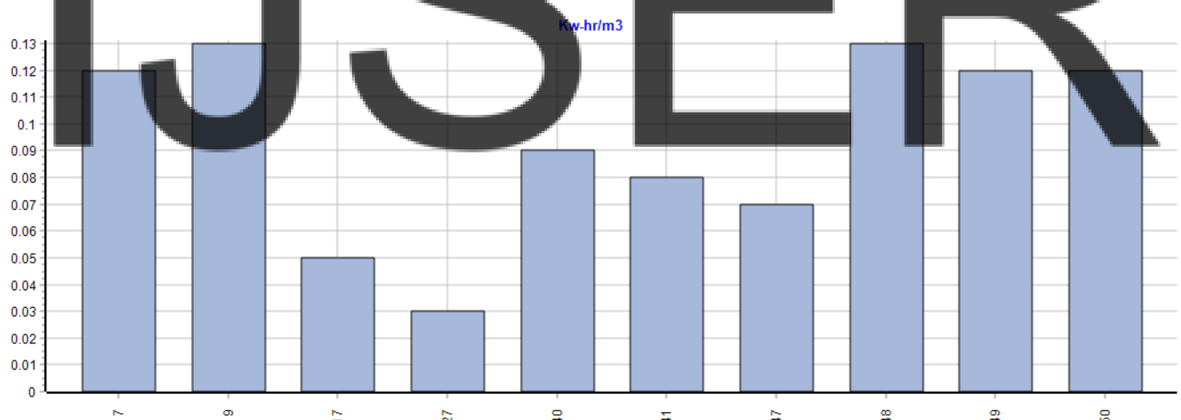


Figure 3.12.6: Histogram depicting Kilowatt hour per meter cube (Kw-hr/m3) for the Pump Links

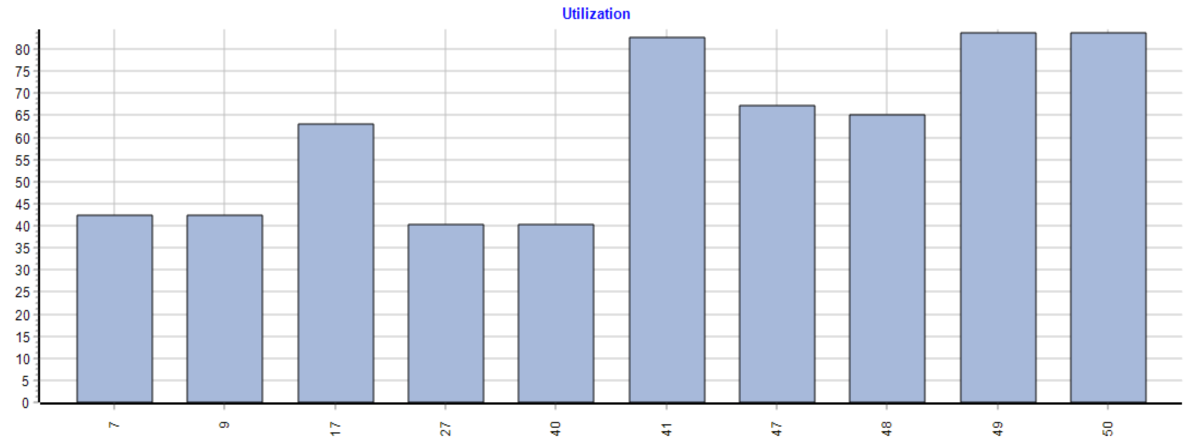


Figure 3.12.7: Histogram depicting rate of Pumps utilisation for the network

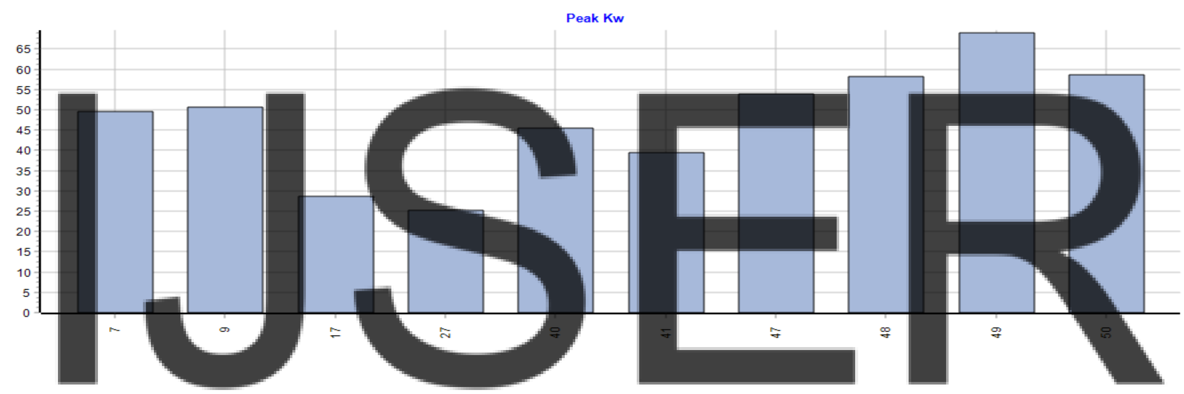


Figure 3.12.8: Histogram depicting Peak Kilowatt (Kw) for the Pumps

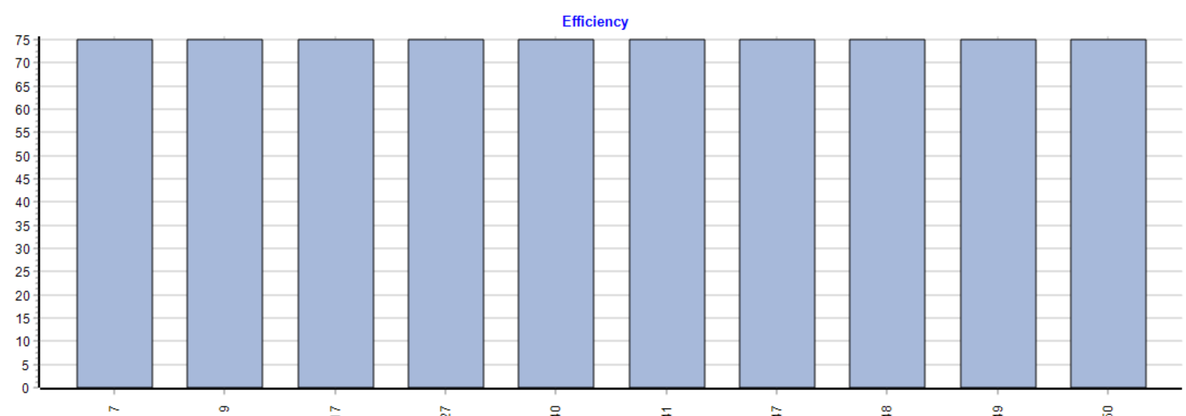


Figure 3.12.9: Histogram depicting Pump Efficiency for the Network

3.3 Calibration of Predicted Epanet Results

Calibration of EPANET 2.0 Sokoto predicted results and the real values measured at the locations within the study area was properly achieved and realized, using the standard methods of calibration through EPANET 2.0 Software, by registering the calibration data at ten (10) points in the network of study, six (6) locations in zone A and four(4) locations in zone B to be calibrated against the predicted values in EPANET 2.0; the network sample locations are 31, 9, 8, 34, 24, 20, 22, 29, 19 and 16. During the calibration process and for effective correlation to be achieved, the wall decay and bulk decay coefficients of the following critical pipes were further changed; pipe 15, 11, 23, 39, 32, 28, 35 and 36 for wall decay and pipes 15, 23, 35 and 36 for bulk decays. The successfully calibrated results of statistics, correlation plot and mean comparison are presented in Table 3.0.

Table 3.0: Comparison Between Observed Chlorine and Modeled EPANET Predicted Chlorine for Sokoto

Sample Point (Metropolis Map)	Sample Nodes (EPANET 2.0)	Sampling Areas (Junctions)	Measured Residual Chlorine (mg/l)	Epanet Residual Chlorine (mg/l)	NSDWQ MPL	WHO MPL
SP1	SN 1	Treatment Plant	0.26	0.26	¬¬ 0.2 - 0.25	0.2 - 0.3
SP2	SN2	Old water works	0.25	0.25	0.2 - 0.25	0.2 - 0.3
SP3	SN3	Bi-water works	0.24	0.24	0.2 - 0.25	0.2 - 0.3
SP4	SN4,5&32	PS 4(Old Market)	0.23	0.23	0.2 - 0.25	0.2 - 0.3
SP5	SN6,7&33	P S 5(Mabera)	0.23	0.23	0.2 - 0.25	0.2 - 0.3
SP6	SN31	Illela Garage	0.18	0.17	0.2 - 0.25	0.2 - 0.3
SP7	SN12	Tudun	0.22	0.21	0.2 -	0.2 - 0.3

		wada			0.25	
SP8	SN28	Unguwan Rogo	0.19	0.23	0.2 - 0.25	0.2 - 0.3
SP9	SN9	Digar Agyare	0.21	0.20	0.2 - 0.25	0.2 - 0.3
SP10	SN8	Gandu Area	0.19	0.21	0.2 - 0.25	0.2 - 0.3
SP11	SN34	Maniru road area	0.21	0.21	0.2 - 0.25	0.2 - 0.3
SP12	SN26	Kanwuri area	0.17	0.21	0.2 - 0.25	0.2 - 0.3
SP13	SN14	Diplomat area	0.11	0.25	0.2 - 0.25	0.2 - 0.3
SP14	SN13	Marina area	0.16	0.24	0.2 - 0.25	0.2 - 0.3
SP15	SN18	Aliyu Jodi	0.16	0.20	0.2 - 0.25	0.2 - 0.3
SP16	SN10	Tswamiyar Dila	0.21	0.20	0.2 - 0.25	0.2 - 0.3
SP17	SN17	Tsalibawa	0.22	0.18	0.2 - 0.25	0.2 - 0.3
SP18	SN15	Rumbukawa	0.21	0.20	0.2 - 0.25	0.2 - 0.3
SP19	SN20	Hajiya Halima area	0.12	0.13	0.2 - 0.25	0.2 - 0.3
SP20	SN21	Runjin Sambo	0.13	0.19	0.2 - 0.25	0.2 - 0.3
SP21	SN30	Minanata	0.18	0.19	¬¬ 0.2 - 0.25	0.2 - 0.3

SP22	SN22	Kofar Atiku	0.22	0.22	0.2 - 0.25	0.2 - 0.3
SP23	SN25	Masallacin Shehu	0.21	0.22	0.2 - 0.25	0.2 - 0.3
SP24	SN16	Aduwar Uwa	0.22	0.20	0.2 - 0.25	0.2 - 0.3
SP25	SN11	Bazzah area	0.20	0.20	0.2 - 0.25	0.2 - 0.3
SP26	SN24	Gidadawa	0.22	0.22	¬¬ 0.2 - 0.25	0.2 - 0.3
SP27	SN27	Alkanci area	0.2	0.19	0.2 - 0.25	0.2 - 0.3
SP28	SN29	Rijiyar Dorawa	0.11	0.20	0.2 - 0.25	0.2 - 0.3
SP29	SN19	Alkammawa	0.16	0.18	0.2 - 0.25	0.2 - 0.3
SP30	SN23	Kofar Taramniya	0.19	0.23	0.2 - 0.25	0.2 - 0.3

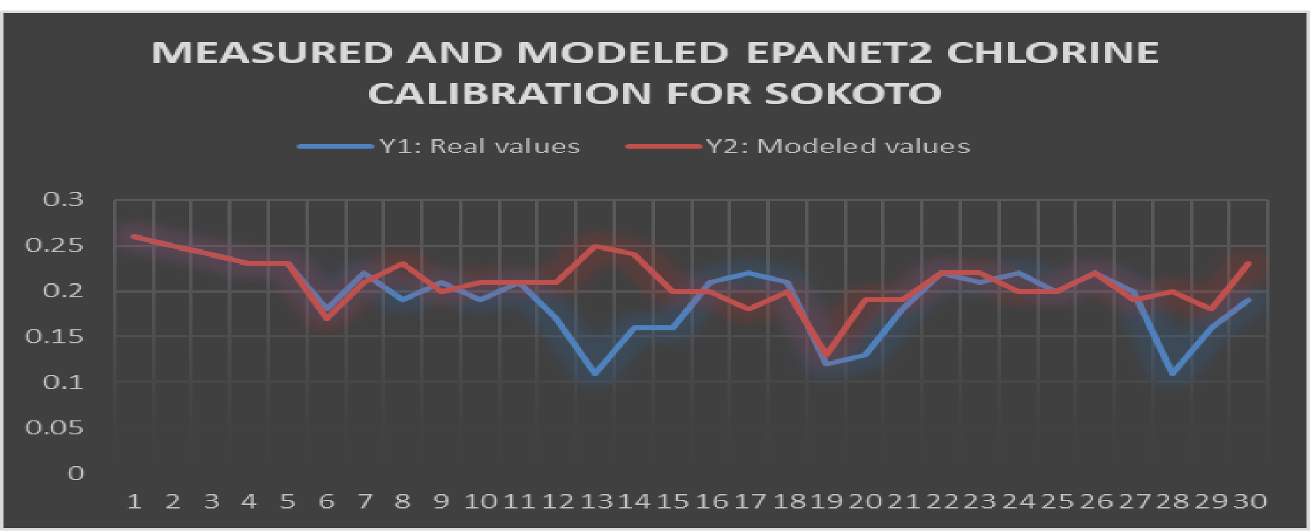


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Table 3.1: Research Calibration Points

S/N	1	2	3	4	5	6	7	8	9	10

Calibration Points	31	9	8	34	24	20	22	29	19	16

Table 3.1.1: Calibration Statistics for Chlorine

S/N	1	2	3	4	5	6	7	8	9	10	Calibration Means
Locations	31	9	8	34	24	20	22	29	19	16	Network Nodes = 10
Observed Chlorine (R_{cl})	0.18	0.21	0.19	0.21	0.21	0.12	0.22	0.16	0.19	0.21	Observed Mean = 0.19
Predicted Chlorine (R_{cl})	0.18	0.20	0.21	0.21	0.22	0.13	0.22	0.18	0.19	0.20	Predicted Mean = 0.19
Observed (R_{cl}) Error	0.003	0.014	0.020	0.004	0.013	0.011	0.001	0.022	0.002	0.014	Observed Rmse Mean = 0.010
Predicted (R_{cl}) Error	0.003	0.014	0.020	0.004	0.013	0.011	0.001	0.022	0.002	0.014	Predicted Rmse Mean = 0.013
Correlation	CALIBRATION CORRELATION BETWEEN MEANS = 0.908(91%)										

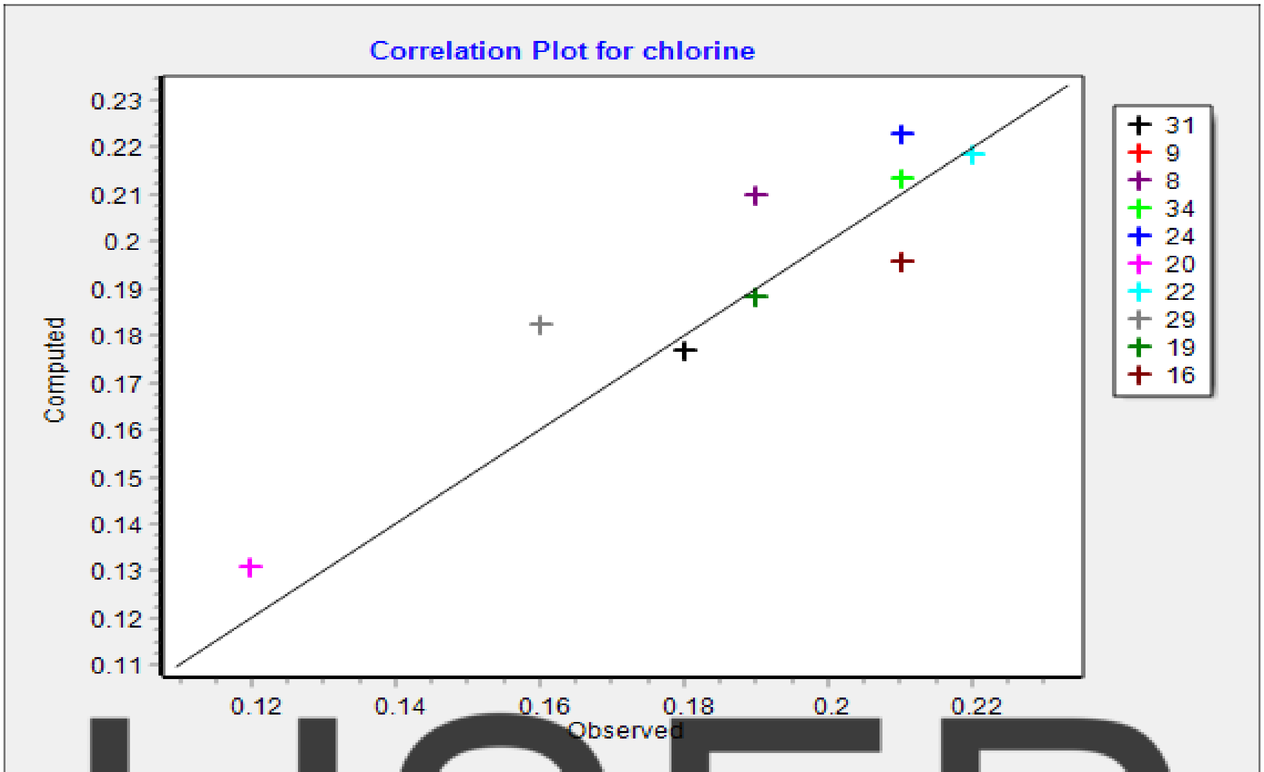

Figure 3.13.1: Correlation plot for the calibrated chlorine

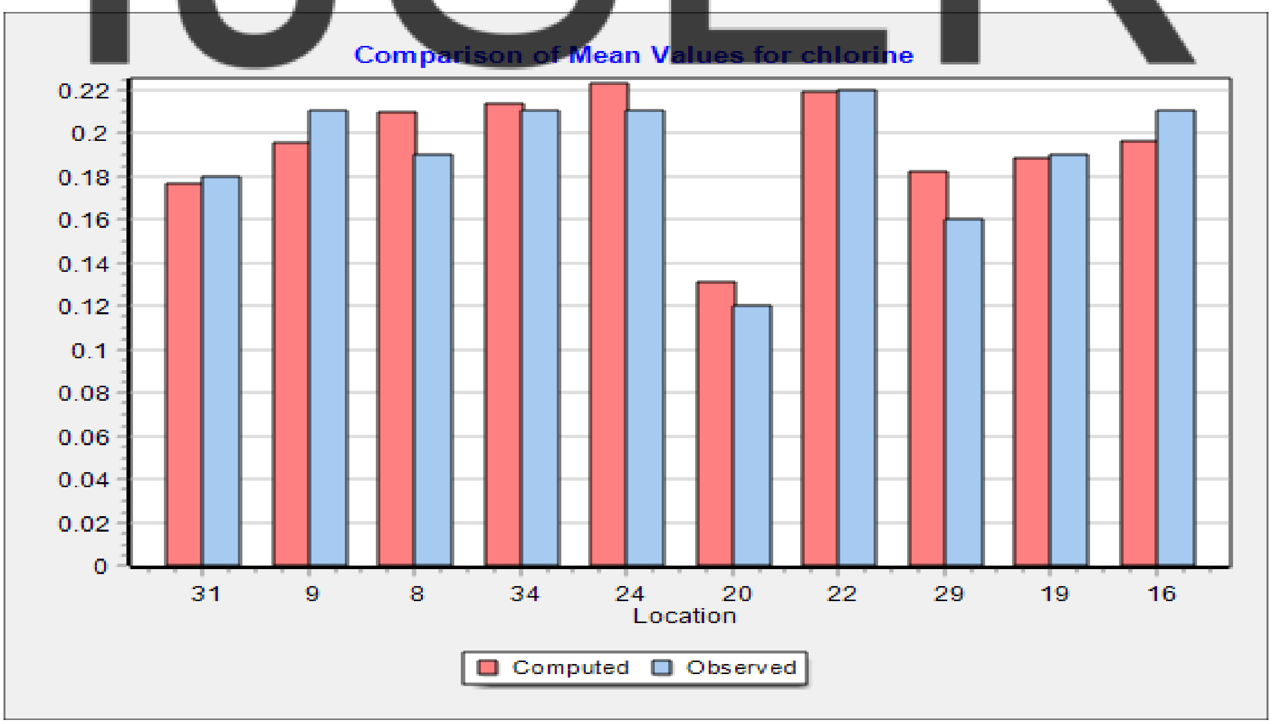

Figure 3.13.2: Comparison of Mean Distribution for the calibrated chlorine

3.4 Validation of the Results:

Validation of the well calibrated EPANET 2.0 Sokoto predicted results and the real values measured at the locations within the study area was accomplished, using the standard methods of Validation through EPANET 2.0 software, by registering the remaining measured chlorine values in the metropolis with the exception of the tanks and reservoir values that are fixed values. The network sample locations are 18, 21, 15, 17, 25, 23, 28, 30, 13, 27, 11, 12 and 14. During the validation process few of the values are not properly read, due to perceived errors in the measured values. The successfully validated results of statistics, validation plot and mean comparison is presented in Table 3.2 and 3.2.1.

Table 3.2: Research Validation Points

S/N	1	2	3	4	5	6	7	8
Validation Points	18	21	17	25	23	30	27	11

Table 3.2.1: Validation Statistics for Chlorine

S/N	1	2	3	4	5	6	7	8	Validation Means
Locations	18	21	17	25	23	30	27	11	Network Nodes = 8
Observed Chlorine(R_{cl})	0.21	0.18	0.22	0.20	0.21	0.19	0.20	0.21	Observed Mean = 0.20
Predicted Chlorine(R_{cl})	0.21	0.19	0.21	0.22	0.23	0.18	0.19	0.21	Predicted Mean = 0.20
Observed R_{cl} Error	0.001	0.009	0.014	0.019	0.015	0.006	0.011	0.003	Observed Rmse Mean = 0.010

Predicted R_{cl} Error	0.001	0.009	0.014	0.019	0.015	0.006	0.011	0.003	Predicted Rmse Mean = 0.011
Correlation	VALIDATION CORRELATION BETWEEN MEANS = 0.648(65%)								

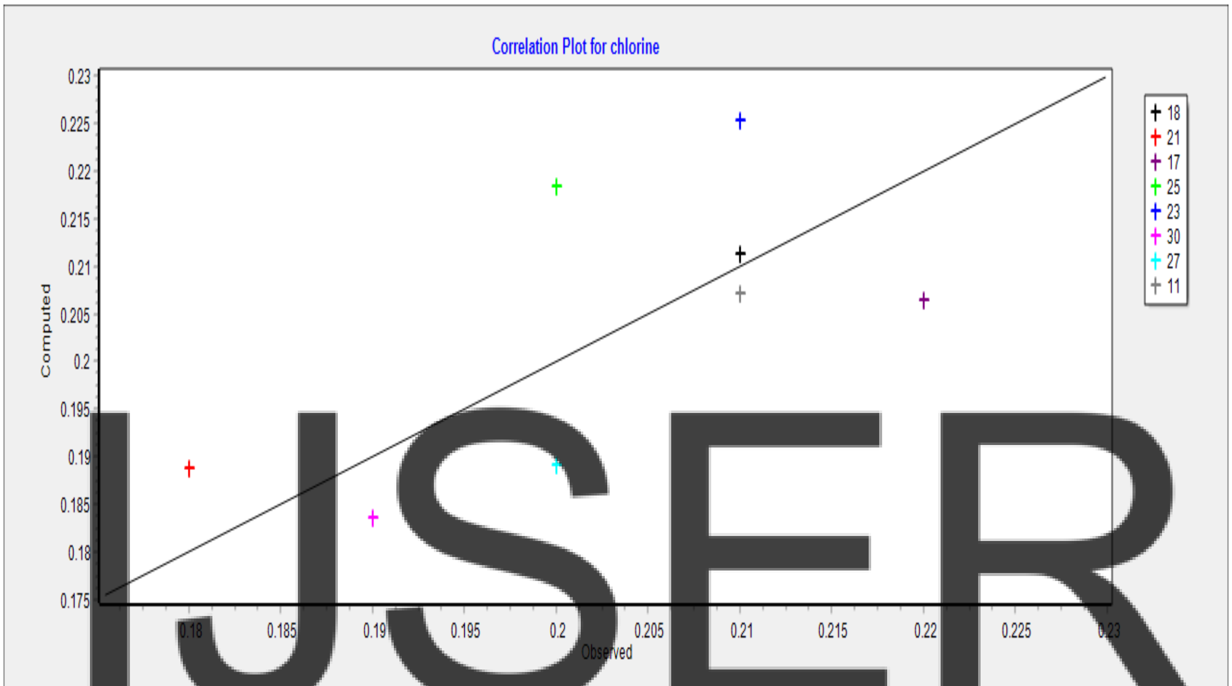

Figure 3.13.3: Correlation plot for the validated chlorine

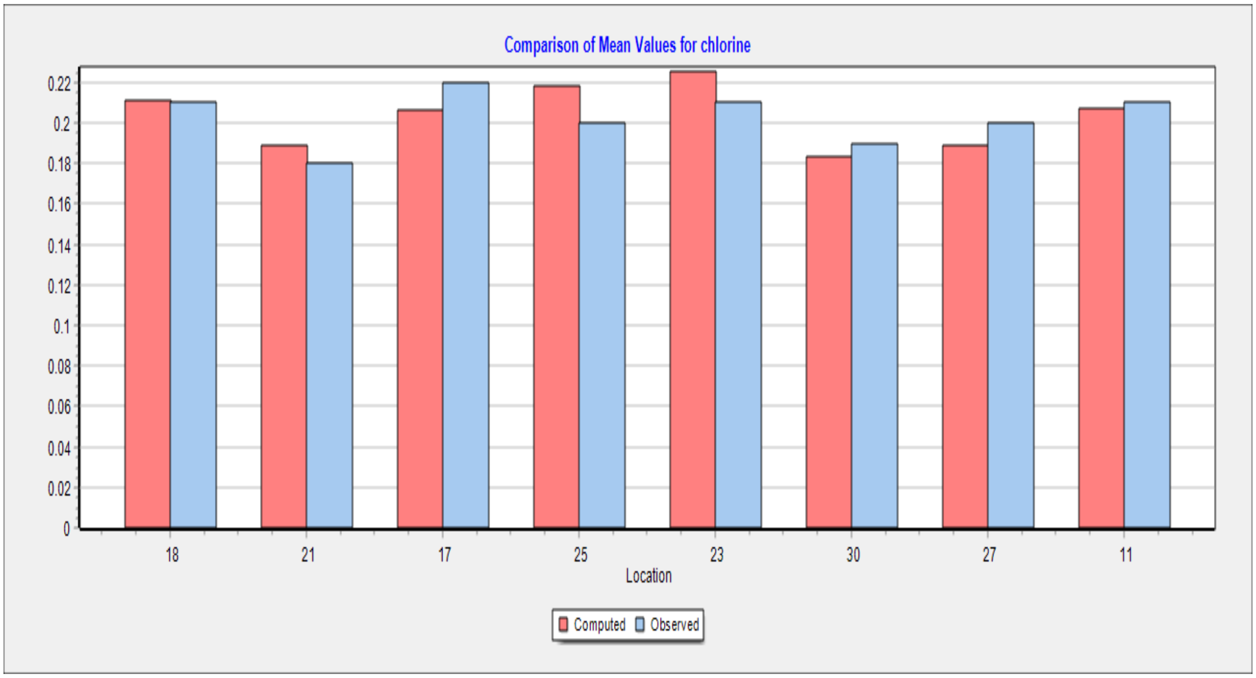

Figure 3.13.4: Validation Comparison plot for chlorine

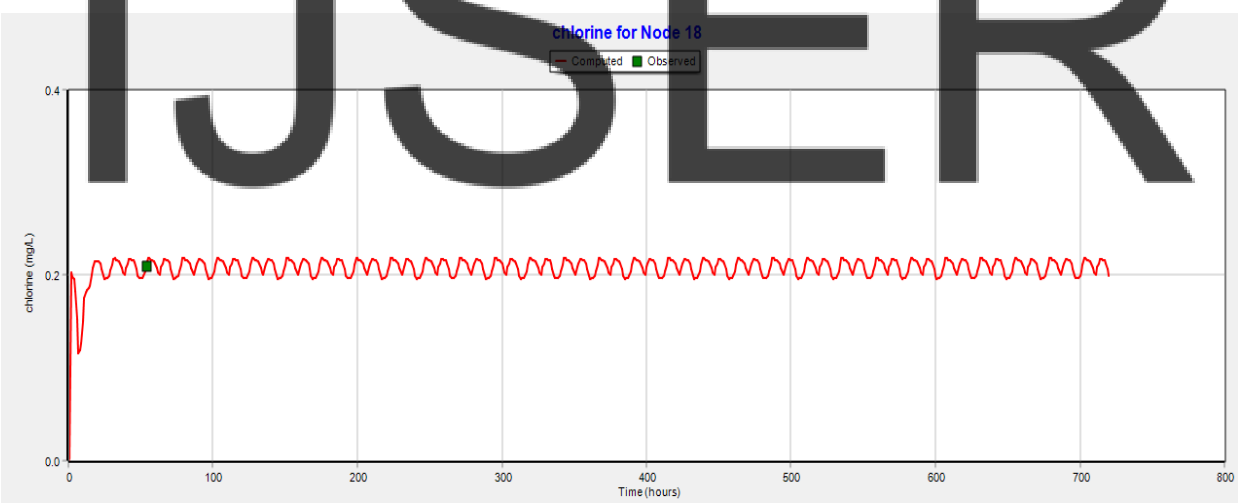

Figure 3.13.5: Simulation plot depicting observed and validated chlorine at N18

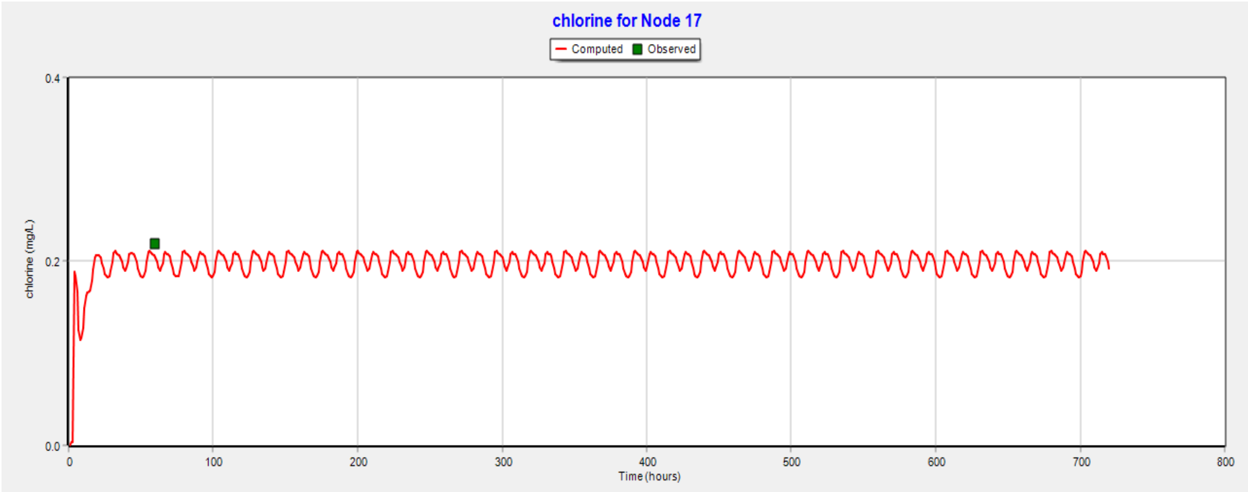

Figure 3.13.6Simulation plot depicting observed and validated chlorine at N17

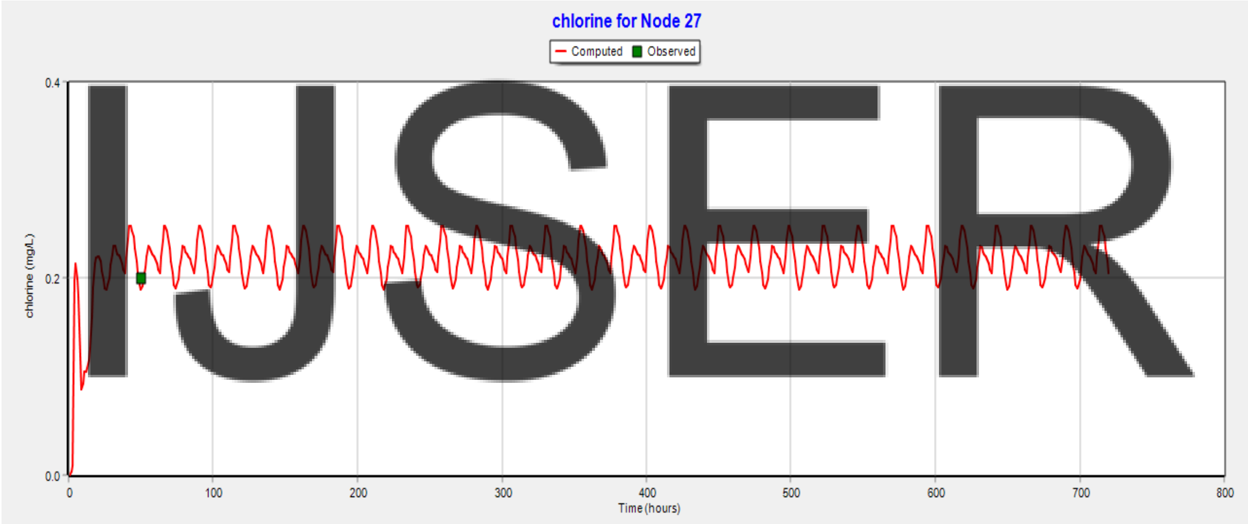

Figure 3.13.7: Simulation plot depicting observed and computed validated chlorine at 27.

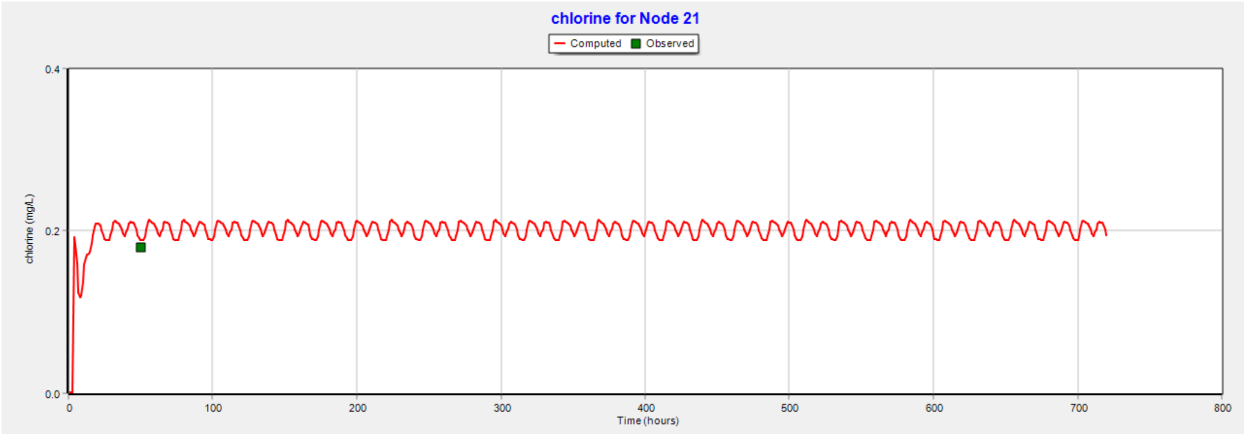

Figure 3.13.8: Simulation plot depicting observed and validated chlorine at N 21

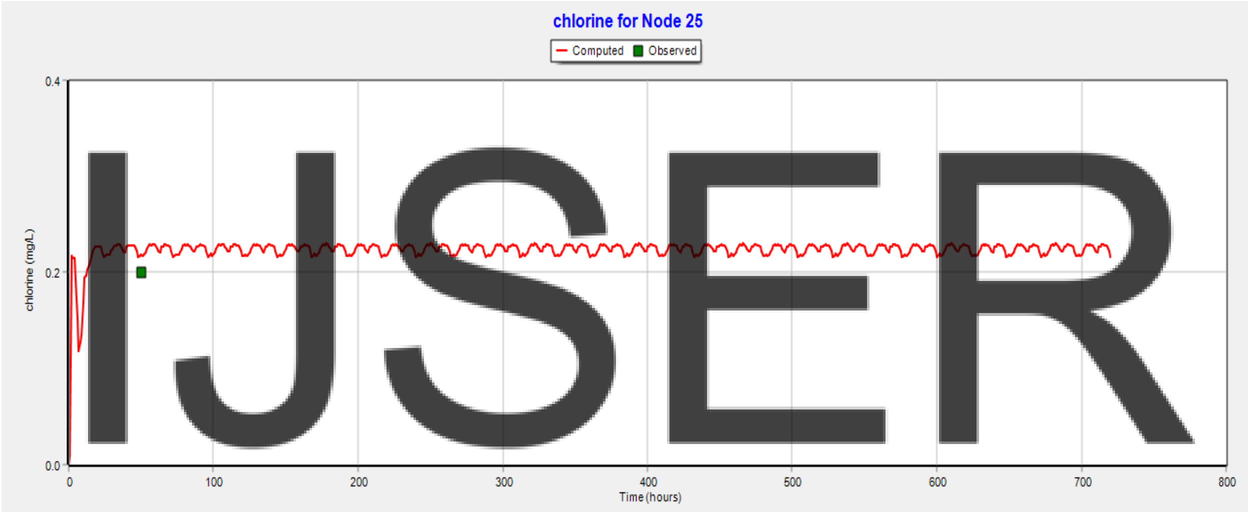

Figure 3.13.9: Simulation plot depicting observed and validated chlorine at node 25.

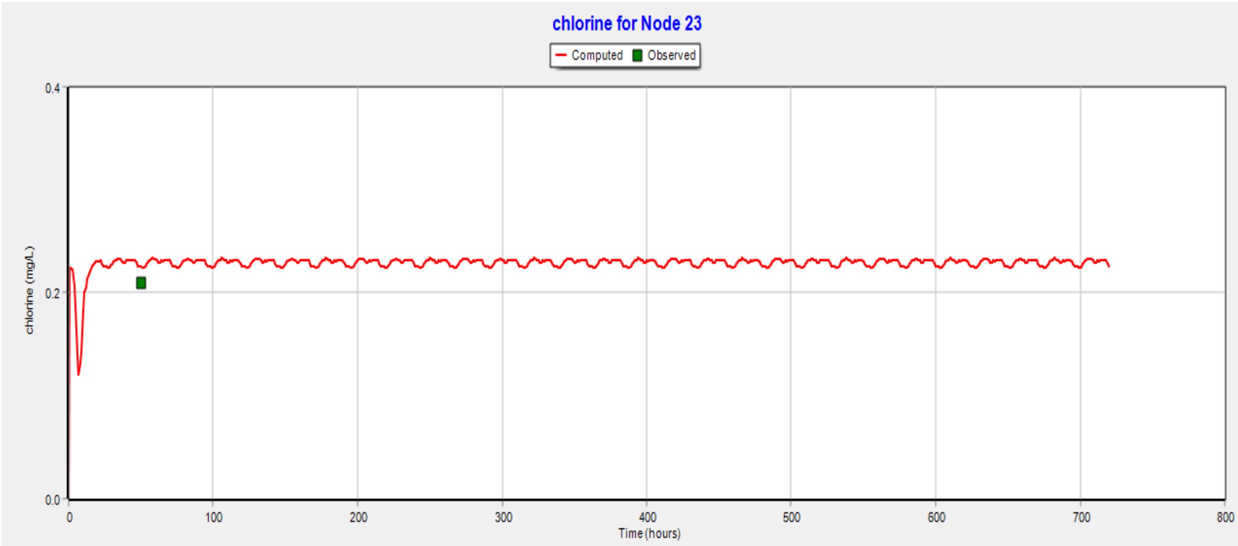

Figure 3.14: Simulation plot depicting observed and validated chlorine at node 23.

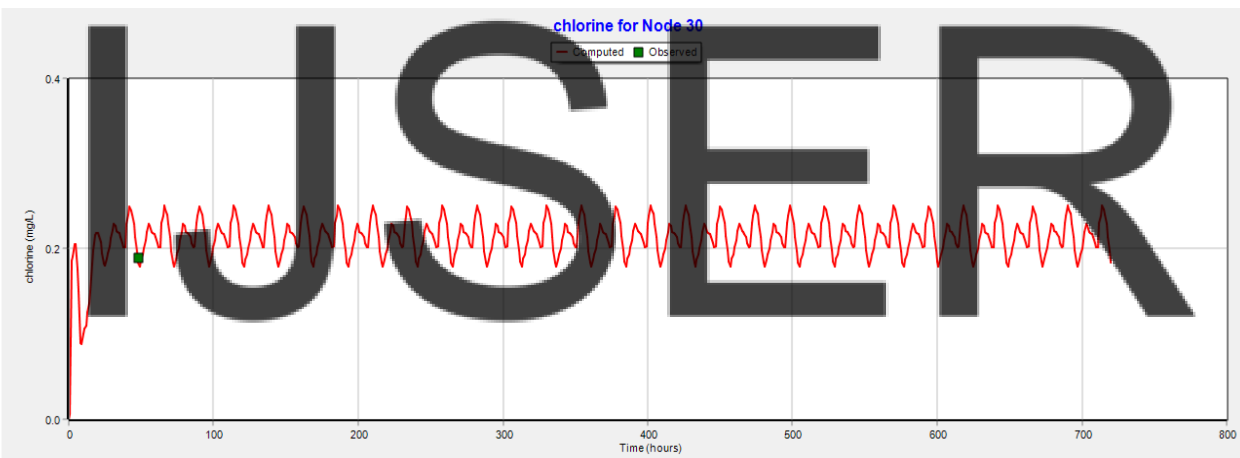

Figure 3.14.1: Simulation plot depicting observed and validated chlorine at node 30.

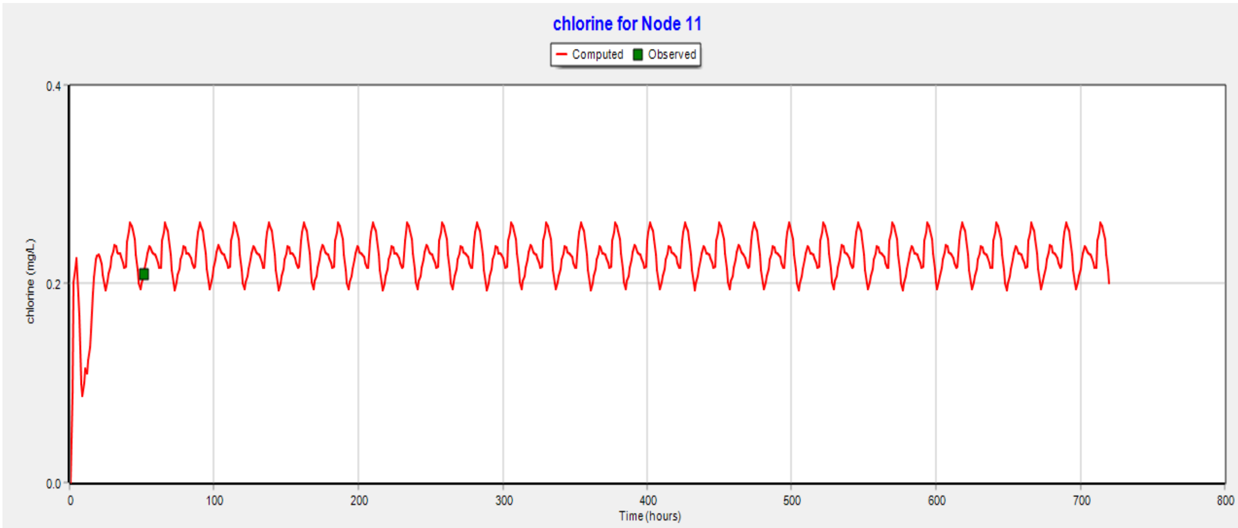

Figure 3.14.2Simulation plot depicting observed and validated chlorine at node 11

3.5 Average Reaction Rate Comparison

Table 3.3 Hydraulically Balanced before Calibration and Validation

S/N	Parameters	Percentages	Ratio
1.	Bulk decay	8.7%	0.3
2.	Wall decay	67.43%	2.3
3.	Tank decay	23.87%	0.8
4.	**Total**	100%	3.4

Table 3.3.1 Hydraulically Balanced after Calibration and Validation

S/N	Parameters	Percentages	Ratio
1.	Bulk decay	12.28%	0.2
2.	Wall decay	55.08%	1.0
3.	Tank decay	32.64%	0.6
4.	**Total**	100%	1.8

4.0 CONCLUSIONS AND RECOMMENDATIONS:

4.1 Conclusions

1. Suitable and reality driven EPANET 2.0 hydraulic and water quality performance model for Sokoto water distribution network was designed.
2. Sokoto Network System calibration and validation of the predicted and observed data was accurately computed and gives calibration correlation R^2 to be **0.908** which is approximately **91%** level of compliance, acceptance and validation R^2 to be **0.648** which is approximately **64%** level of acceptance and compliance.
3. Validated EPANET 2.0 distribution system average chlorine decay rate for Sokoto at the pipe wall is 55.08%, at the bulk of flow is 12.28% and at the system tanks is 32.64%,

4.2 Recommendations

1. That, Sokoto state government is advice to change the critical pipes; 31, 9,8,34, 24, 20, 22, 29, 15, 11, 23, 39, 32, 28, 35 and 36 to satisfy the bulk and wall decay changes.
2. That, water supply providers e.g. government agencies, should take adequate and proper measures in solving the problem of negative pressure conditions associated with most water distribution networks and in turn affecting the residual chlorine in the system.

4.3 Contribution To Knowledge

1. A well designed hydraulic and water quality model for Sokoto water distribution system and its environs was developed.
2. Minimum chlorine concentration of the network is achieved in the simulation and can be regulated and increase in terms of deficiency by adding more chlorine at nearby distribution tank.

5.0 References

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