TECHNICAL PROGRESS REPORT

Remediation and Treatment Technology Development and Support for DOE Oak Ridge Office: XPSWMM Model Configuration

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FIU | Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY

Task 1: EFPC Model Update, Calibration, Uncertainty Analysis

Subtask 1.3: Surface Water Flow and Contaminant Transport Model of ORNL 4500 Area

Introduction:

In order to understand the transport of contaminants, it is critical to understand the flow of water within the area of interest. Thus, a conceptual stormwater management model is being developed for the contributing drainage areas of Outfall 211 as well as sources from the adjacent buildings, such as cooling water and condensate from various AC units and discharge from the Creep Laboratory (Building 4500S). The water leaving the Creep Laboratory is treated with chlorine prior to its discharge via storm laterals into the main storm trunk line. A dechlorinator was therefore placed after Outfall 211 in order to reduce the chlorine concentration prior to its discharge into WOC. In 2007, Building 4501 was known as the primary location of Hg contamination. (ChemRisk, 1999a)

The model will develop an approach that can be extendible to the Y-12 National Security Complex. ORNL is acting as a test bed for Y-12 because the area of interest is at a smaller scale at ORNL and both facilities were built using similar construction and drainage methods. The model will allow for flood risk analysis of the contributing areas.

The area of interest is approximately 5 acres and consists of a network of closed conduits discharging into a free surface creek. The flow is considered unsteady open channel flow because both the closed conduits and the creek are open to atmospheric pressure. The system is modeled as one-dimensional gradually varied flow. The program chosen to develop the conceptual stormwater management model is XPSWMM which is Microsoft Windows version of the Environmental Protection Agency (EPA) stormwater management modeling (SWMM) tool.

1. XPSWMM Model

XPSWMM uses a spatially distributed link/ node network to analyze the hydraulic, hydrologic, and quality of a stormwater or wastewater system. The XPSWMM software package applies the Saint-Venant equations to solve for the one-dimensional unsteady open channel flow. The Saint-Venant equations are composed of the continuity, momentum, and energy equations. However, in order for the equations to hold true the following six fundamental assumptions must apply:

1) The flow is one dimensional, the velocity is uniform in a cross-section and the transverse free-surface profile is horizontal;
2) The streamline curvature is very small and the vertical fluid accelerations are negligible; resulting in the pressure distributions are hydrostatic;
3) The flow resistance and turbulent losses are the same as for a steady uniform equilibrium flow for the same depth and velocity, regardless of trends of the depth;
4) The bed slope is small enough to satisfy the following approximations:
    a. $\cos\Theta \approx 1$
    b. $\sin\Theta \approx \tan\Theta \approx \Theta$

5) The water density is constant and
6) The Saint-Venant equations were developed for fixed boundary channels; that is, sediment motion is neglected. (Chanson, 2004)

2. Modeling Parameters

XPSWMM is equipped with three modes the hydraulic, runoff, and sanitary modes. Both the hydraulic and the runoff modes are utilized in this model. The dialogs will request certain information depending on which mode is active.

Node data, conduit shapes, pumps, control structures and weirs may be modeled in the hydraulic mode. The node dialog requests the spill crest elevation where it can be the manhole elevation for a manhole, inlet elevation for an inlets, or top of pipe for a junction box. For the purpose of this project, a junction box is considered as a point where the storm pipe changes direction without a manhole or inlet or where the storm drain enters the main storm line. There is a dialog for the conduit information and selection of various shapes of pipe along with an aid to visualizing the conduit profiles.

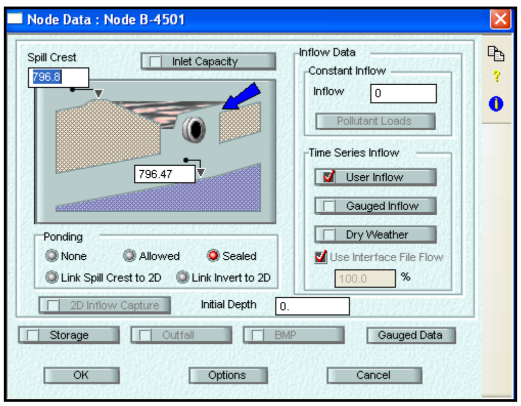

Figure 1 XPSWMM Node Data Dialog

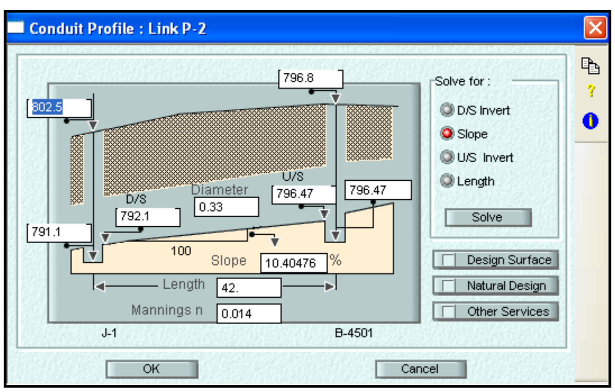

Figure 2 XPSWMM Conduit Profile

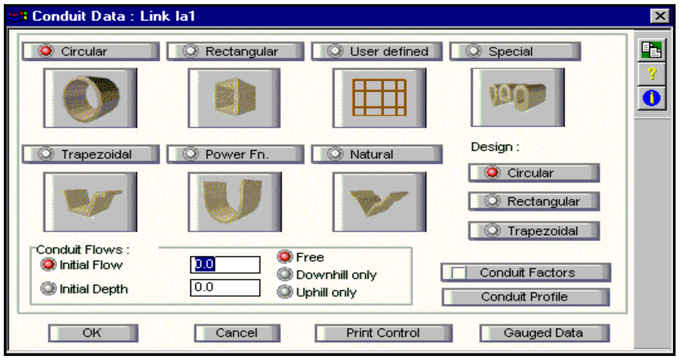

Figure 3 XPSWMM Conduit Shapes

In the runoff mode, drainage areas are delineated for the inlets via sub-catchments. One inlet can have up to five sub-catchment areas where each sub-catchment may have varying areas, impervious percentage, width, and slope. The various sub-catchments will make up the node catch basin incorporating the higher elevation contour surrounding the node. The sub-catchments are the areas that are directly connected to the inlet and will contribute runoff during the simulated rainfall events.

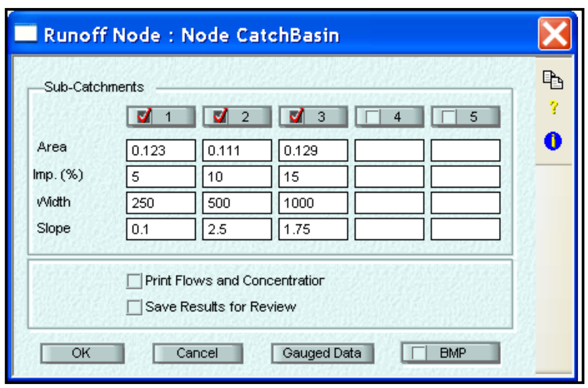

Figure 4 Sub-catchment Dialog

The network is made up of a series of links and nodes, a link being a conduit such as a storm drain, storm pipe, or culvert that conveys water from one node to another. Nodes are considered to intake stormwater or other discharges, in this case would be the A/C units condensate and cooling water or the chlorinated discharge water from the Creep Laboratory in Building 4500S, which would be either building drains, roof drains, manholes, inlets, or junction boxes. The required input data for the conveyance through the conduits are the Manning's roughness coefficient, slope, downstream invert, upstream invert, pipe length and spill crest elevations.

The Node and Link XP Tables used within the model are attached within the Appendix.

2a. Topography

As an industrial area, ORNL is composed of mostly impervious area with sparse pervious areas. The area bordering the area of interest ranges in elevation from 780 ft NGVD to 855 ft NGVD as shown on the DTM. However, the area of interest is relatively flat ranging from 780 ft NGVD to 810 ft NGVD and includes the following ORNL buildings:

1) 4500N Wings 1, 2, and part of Wing 3
2) 4500S Wings 1 , 2, and part of Wing 3
3) 4501
4) 4505
5) 4507
6) 4508
7) 4556 (note Building 4556 is considered a manmade structure)

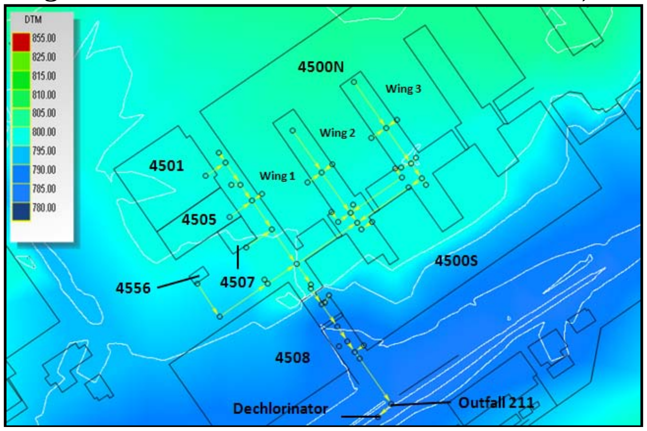

Figure 5 XPSWMM Digital Terrain Model

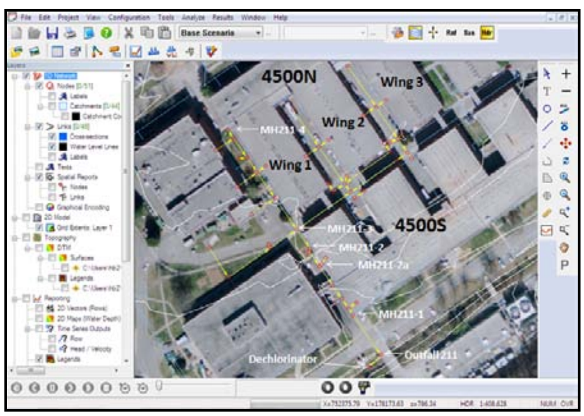

Figure 6 XSPWMM Model Main Storm Line

There is only one sump connecting to Outfall 211 today which is Sump P. Sump P is located within Building 4556 and is only active when a large rainfall event occurs. A 4" VP connects to a 10" VP which conveys water into MH211-3 located at the northwest corner of Building 4500S. The main storm line runs west of 4500N and 4500S and contains MH211-1, MH211-2, MH211-2a, MH211-3, MH211-4, and Outfall 211. It begins at MH211-4 and ends at Outfall 211. From MH211-4 to MH211-3, the main storm line is constructed of 15" RCP. South of MH211-3 the line is 30" RCP. Outfall 211 is a culvert located under a bridge. However, the water is not discharged into WOC at that location. There is a 65" long, 13.5" high metal plate acting as a weir directing water to discharge through an 8" PVC pipe. The 8" PVC pipe conveys the water into the dechlorinator. The 8” PVC is reduced to a 4” PVC where the water is disinfected via the dechlorinator.

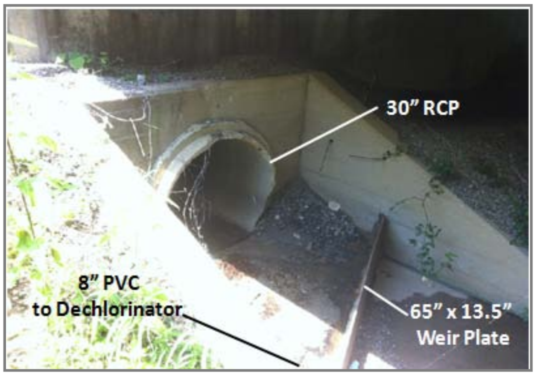

Figure 7 Outfall 211

Figure 8 WOC under Bridge

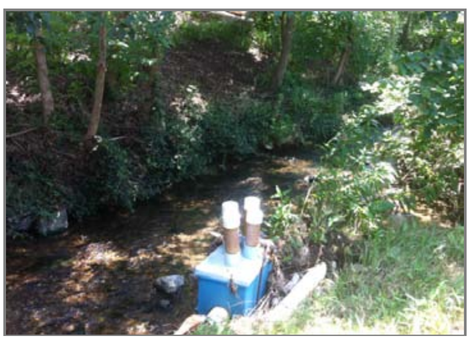

Figure 9 Dechlorinator in WOC

2b. Open Channel Flow

The conveyance of water within the system is solved by the Manning’s formula for open channel flow through the conduits:

$$v = \frac{1.49}{n} R^{\frac{2}{3}} \sqrt{S}$$

$$Q = v * A$$

$$R = \frac{A}{P}$$

Where Q represents water flow (cfs), v is the velocity (fps), A is the cross-sectional area of flow (sf), n is the Manning's coefficient (dimensionless), R is the hydraulic radius (ft), and S is the slope of the water surface or the linear hydraulic head loss (ft/ft). The hydraulic radius is equal to the cross-sectional area of flow divided by the wetted perimeter (ft) as shown in the third equation above. The wetted perimeter for partially filled circular conduits may be found by the following information and measurements:

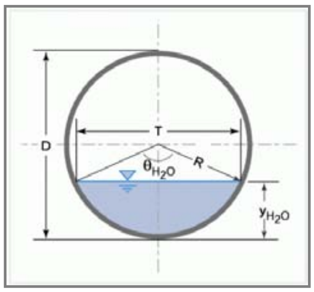

Figure 10 Partially Filled Circular Conduit

Angle from the centerline to the water level, $\Theta = cos^{-1}\left(1 - \frac{y}{r}\right)$
Depth of water in culvert, $y = r(1 - \cos\Theta)$
Cross-sectional area of flow, $A = r^2(\Theta - \cos\Theta\sin\Theta)$
Wetted Perimeter of water, $P = 2r(\Theta)$
Top width of water surface, $T = 2r(\sin\Theta)$

The Manning's roughness coefficient is based on the material of the pipe or the type of channel ranging from a minimum, normal, and maximum number. It is inversely proportional to the flow rate where the smaller the coefficient the larger the flow due to the friction caused by the channels roughness. The network contains the following types of pipes:

- Wrought iron
- Vitrified clay
- Concrete pipe
- Reinforced concrete pipe
- Polyvinyl chloride

The Node and Link XP Tables are attached in the Appendix indicating the preliminary Manning's coefficient chosen for the pipes.

2c. Infiltration

The Horton Infiltration has been chosen to calculate the pervious areas. The Horton equation is as follows:

$$F_p = F_c + (F_0 - F_c)e^{-kt}$$

Where:
Fp = infiltration rate into soil, in./hr (mm/hr)
Fc = minimum or asymtopic value of Fp, in./hr (mm/hr)
Fo = maximum or initial value of Fp, in./hr (mm/hr)
t = time from beginning of storm, sec
k = decay coefficient, 1/sec

The ORNL site is composed of buildings, pavement, and minor pervious area. It is surrounded by ORR's wooded lands. Soils in the area are a mixture of reddish-brown clays and silts resulting from in-situ weathering of shaley limestone bedrock. Also, the model will only consider dry weather conditions as opposed to wet weather conditions where the antecedent precipitation nine days prior to the start date is considered. Thus, due to the fact that the soils are clays and silts and dry weather is considered the model utilizes XPSWMM default values for the Horton Infiltration equation as shown below.

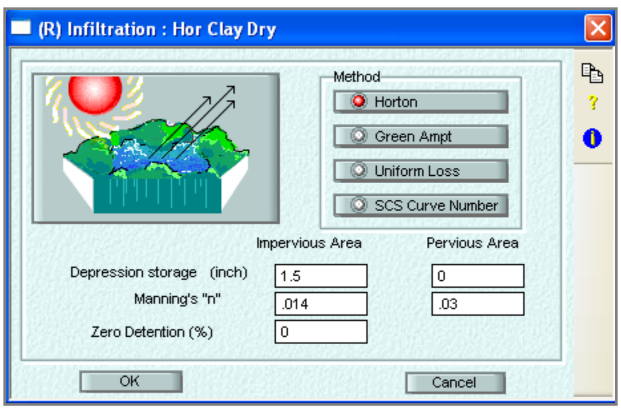

Figure 10 Horton Infiltration Dry Clay Parameter

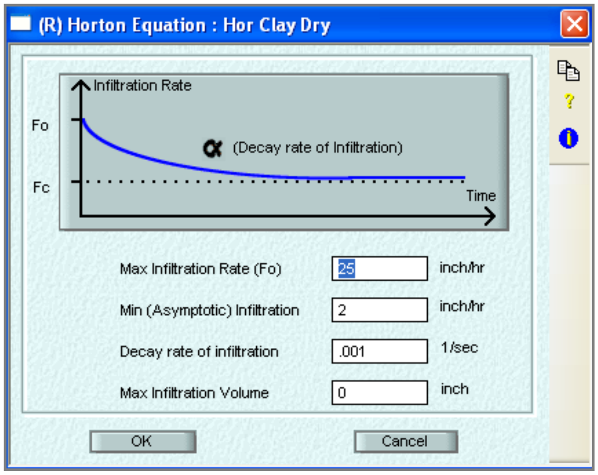

Figure 11 Horton Equation Dry Clay Parameter

2d. Rainfall

U.S. Natural Resources Conservation Service (NRCS) formerly known as the U.S. Soil Conservation Services (SCS) method is used to compute rainfall distributions. The City of Knoxville (adjacent to the City of Oak Ridge) Land Development Manual suggests that the SCS unit hydrograph be utilized for the routing of the storm events. The unit hydrograph will be multiplied by the precipitation for each storm event in order to produce the hydrograph for its corresponding rainfall event. The area of interest falls within Region II; thus, the SCS Type II storm event has been chosen for the following rainfall events will be routed in order to assess flood risk in the area:

- 25 year – 24 hour; P = 5.47 inch
- 100 year – 24 hour; P = 6.85 inch
- 500 year – 24 hour; P = 8.60 inch

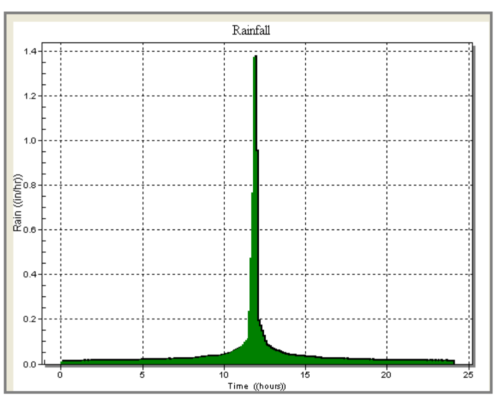

Figure 12 SCS Type II Unit Hydrograph

2e. Routing Method

The Kinematic Wave Equation is utilized for overland flow routing where XPSWMM takes into account the area, slope and width of the sub-catchment areas.

2f. Boundary Conditions

Tail water conditions (time series data) for Outfall 211 data mining is currently underway via OREIS website in order to assess the actual WOC elevations during the routing of the storm events.

2f. Model Assumptions

Based on the original drawings, the newer set of drawings, the Atlas drawings, discrepancies and unknown information, the following assumptions are made:

1. The original drawings indicate that the Outfall 211 drainage system begins from the east between 4500N and 4500S Wings 2 and 3. However, the atlas drawings show it interconnected with the drainage system to the east. This model will be in accordance with the original drawings where Outfall 211's drainage system stands alone and begins from the east at the manhole located between 4500N and 4500S Wings 2 and 3.
2. The Atlas drawings do not show the existing inlet to the west of MH211-3.
3. The Atlas drawings indicate that the inlet east of 4500N Wing 1 is shown to the west of the manhole located at the north-south centerline; however, it is located to the east of the north-south centerline.
4. The Atlas drawings do not show or have no symbol for the two inlets located east of 4500N Wing 2.
5. There are unknown inverts, manhole elevations, and inlet elevations throughout the system where reasonable assumptions will be made from analysis of surrounding or like data.
6. Assumptions will be made for the building area contributing to the roof drains. A single lateral for each building will be shown in places where there are multiple storm laterals/roof drains for simplistic purposes to begin. There will be a constant 2gpm/lateral for condensate and/or cooling water discharging into the system as per the estimate provided by the ORNL Engineering Department.

References

Chanson, H. Environmental Hydraulics of Open Channel Flows, Burlington: Elsevier Butterworth-Heinemann, 2004.

ChemRisk. (1999a). Radionuclide Releases to the Clinch River from WOC on the Oak Ridge Reservation—An Assessment of Historical Quantities Released, Off-site Radiation Doses, and Health Risks, Task 4. Reports of the Oak Ridge Dose Reconstruction, Volume 4. Tennessee Department of Health.

City of Knoxville. 2003. Land Development Manual, Chapter 9 Stormwater Design.

APPENDIX

Table 1.NODES

Name	Subcatchment	Ground Elevation (Spill Crest) ft	Invert Elevation ft	Ponding Type	Width ft	Area ac	Impervious Percentage %
OF-211		786.441	780.74	Allowed	0	0	0
MH211-4		801.7	791.4	Sealed	0	0	0
MH211-3		799.5	788.1	Sealed	0	0	0
MH211-2		800.4	791.9	Sealed	0	0	0
I-2	1	799	795.8	Allowed	18	0.065	80
I-2	2				40	0.237	80
I-2	3				5	0.065	95
I-2	4				10.2	0.086	100
I-2	5				13.2	0.108	5
T-2	1	800	796	Allowed	52.9	0.151	100
MH-5		799	790.4	Sealed	0	0	0
T-3	1	800	796	Allowed	18	0.14	100
T-3	2				14.2	0.075	100
T-3	3				20	0.14	100
MH-7		800	791.3	Sealed	0	0	0
I-4	1	799	795.5	Allowed	14	0.161	100
I-4	2				17.9	0.054	95
I-4	3				15.5	0.075	95
I-8	1	798.2	796.7	Allowed	8.8	0.011	100
I-9	1	798	796.5	Allowed	5.3	0.065	100
I-9	2				5.3	0.011	100
I-6	1	800	791	Allowed	12.15	0.043	95
I-6	2				7.7	0.065	95
MH-8		797.2	791.9	Sealed	0	0	0
I-1	1	800.573	795	Allowed	43.3	0.065	5
I-1	2				52.2	0.108	5
J-2		794.4	790.4	Sealed	0	0	0
B-4556	1	796.1	795.75	Sealed	10.6	0.011	100
J-7		801	783.5	Sealed	0	0	0
J-8		792.941	783.2	Sealed	0	0	0
J-10		784.9	782.1	Sealed	0	0	0
B-4500S_B	1	786.5	786	Sealed	26.7	0.183	100

Name	Subcatchment	Ground Elevation (Spill Crest) ft	Invert Elevation ft	Ponding Type	Width ft	Area ac	Impervious Percentage %
B-4500S_A	1	789.6	789	Sealed	37.1	0.269	100
MH-2A		793.16	785.5	Sealed	0	0	0
J-6		795.8	795.45	Sealed	0	0	0
J-5		795.2	793.7	Sealed	0	0	0
B-4500N_E	1	799.2	798.7	Sealed	12.5	0.054	100
J-13		798.8	798.2	Sealed	0	0	0
MH-6		800	795.2	Sealed	0	0	0
B-4500N_B	1	799.6	799.1	Sealed	13	0.043	100
J-11		796	795.5	Sealed	0	0	0
B-4507	1	793.55	793	Sealed	16.7	0.032	100
J-4		799.5	789	Sealed	0	0	0
B-4501	1	796.8	796.47	Sealed	32.2	0.183	100
J-1	1	802.5	791.1	Sealed	22.6	0.086	100
B-4505	1	797.7	796.8	Sealed	19	0.086	100
J-3		797	789.9	Sealed	0	0	0
B-4500N_A	1	799.75	799.2	Sealed	15.3	0.161	100
I-3	1	790.423	782.7	Allowed	14.9	0.022	90
I-3	2				9.9	0.075	95
B-4500N_C	1	800.15	799.6	Sealed	24.1	0.129	100
J-12		796.6	795.3	Sealed	0	0	0
B-4500N_D	1	800.15	799.6	Sealed	47	0.183	100
B-4500N_F	1	800.1	799.6	Sealed	32	0.14	100
J-14		794.8	793.5	Sealed	0	0	0
B-4500N_G	1	800.1	799.6	Sealed	22.4	0.14	100
I-10	1	803.147	795.7	Allowed	20.3	0.075	100
I-10	2				12.8	0.032	100
I-10	3				20.3	0.075	100
I-10	4				14	0.032	100
I-5	1	802.207	795.4	Allowed	18.4	0.054	100
I-5	2				15.6	0.022	100
I-5	3				22.3	0.075	100
I-5	4				22.5	0.075	100
B-4500S_C	1	797	796.5	Sealed	48.6	0.129	100

Name	Subcatchment	Ground Elevation (Spill Crest) ft	Invert Elevation ft	Ponding Type	Width ft	Area ac	Impervious Percentage %
MH211-1		789	782	Sealed	0	0	0
J-9		785.1	782.3	Sealed	0	0	0
T-1	1	790	786	Allowed	9.5	0.043	100
Dechlor		780.33	780	Sealed	0	0	0
J-15		780.67	780	Sealed	0	0	0
J-16		780.67	780	Sealed	0	0	0
B-4500S_E	1	797.4	796.9	None	52.5	0.14	100
B-4500S_D	1	797.4	796.9	None	64	0.14	100
I-11	1	798.2	797.5	None	50	0.054	100

Table 2. LINKS

Name	Shape	Length ft	Roughness	Conduit Slope	Diameter (Height) in
P-51	Circular	5.2	0.012	14.231	8.04
P-1	Circular	22	0.015	1.364	15
P-15	Circular	41.5	0.013	4.819	30
P-16	Circular	6.6	0.014	127.273	30
P-12	Circular	8	0.014	26.25	15
P-37	Circular	7.8	0.014	39.744	6
P-27	Circular	41.56	0.014	8.422	24
P-50	Circular	14.5	0.014	32.414	8.04
P-41	Circular	28.14	0.014	1.066	24
P-31	Circular	17	0.014	1.765	15
P-43	Circular	19	0.014	25.263	15
P-44	Circular	14.1	0.014	32.624	15
P-40	Circular	115.9	0.014	0.259	24
P-42	Circular	34.37	0.014	1.746	15
P-4	Circular	17.1	0.014	26.901	12
P-5	Circular	36	0.015	1.389	15
P-14	Circular	71.7	0.014	0.418	3.996
P-17	Circular	30.4	0.014	0.987	30
P-20	Circular	45	0.014	1.111	30
P-25	Circular	11.7	0.014	0.855	30
P-24	Circular	20.37	0.014	19.146	6
Name	**Shape**	**Length ft**	**Roughness**	**Conduit Slope**	**Diameter (Height) in**

P-19	Circular	16.1	0.014	21.739	6
P-18	Circular	6.6	0.014	34.848	6
P-13	Circular	100.6	0.014	0.596	3.996
P-11	Circular	59.3	0.014	9.444	15
P-39	Circular	21.1	0.014	2.37	6
P-38	Circular	115.9	0.014	2.588	6
P-28	Circular	21.8	0.014	10.55	15
P-30	Circular	21.35	0.014	16.862	6
P-29	Circular	27.9	0.014	1.075	6
P-9	Circular	52	0.014	5	6
P-10	Circular	79.4	0.015	1.134	15
P-2	Circular	42	0.014	10.405	3.96
P-3	Circular	48.6	0.015	1.44	15
P-6	Circular	51	0.014	7.451	9.996
P-8	Circular	64.3	0.015	1.4	15
P-7	Circular	21	0.014	44.286	6
P-21	Circular	29.1	0.014	1.375	30
P-33	Circular	32.6	0.014	13.19	6
P-32	Circular	88.5	0.014	0.113	15
P-34	Circular	24.7	0.014	17.409	6
P-47	Circular	32.34	0.014	18.862	6
P-46	Circular	80.29	0.014	1.993	15
P-48	Circular	25.3	0.014	24.111	6
P-49	Circular	104.7	0.014	2.101	15
P-35	Circular	90.1	0.014	0.111	15
P-36	Circular	24.6	0.014	2.033	6
P-26	Circular	100.3	0.014	1.256	30
P-23	Circular	20.2	0.014	0.99	30
P-22	Circular	18.27	0.014	20.252	6
P-52	Circular	24	0.012	0	8.04
P-53	Circular	10.1	0.012	0	3.96
P-54	Circular	22.8	0.014	3.947	6
P-55	Circular	25.3	0.014	3.557	6
P-56	Circular	108.2	0.014	1.386	8.04