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Revision 0

Analysis of Stormwater Management for Potential Land Development Scenarios for the 300 Area Land Conveyance Site

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Environmental Calculation File

Analysis of Stormwater Management for Potential Land Development Scenarios for the 300 Area Land Conveyance Site

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Abbreviations and Acronyms

CoR	City of Richland
EA	Environmental Assessment
ECF	Environmental Calculation File
EIS	Environmental Impact Statement
ft	feet
HISI	Hanford Information System Inventory
in/hr	inch(es) per hour
LID	Low Impact Development
MSA	Mission Support Alliance
NAVD 88	North American Vertical Datum of 1988
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
SCS	Soil Conservation Service
SWMM	Storm Water Management Model
TMR	Telescopic Mesh Refinement
TRIDEC	Tri-City Development Council
USEPA	United States Environmental Protection Agency
WA ECY	Washington State Department of Ecology
WSDOT	Washington State Department of Transportation

1 Purpose

The purpose of this Environmental Calculation File (ECF) is to provide an estimate of infiltration from stormwater ponds for input in a Telescopic Mesh Refinement (TMR) of an existing MODFLOW model for the Hanford 300 Area Land Conveyance Site. The infiltration values are used by the TMR model to simulate recharge and groundwater elevations in response to concentrated infiltration from the stormwater ponds. Stormwater modeling was applied to determine both conservative (high) and low impact development infiltration values from stormwater ponds in a proposed light industrial park at the 300 Area Land Conveyance Site. This calculation was performed in support of the National Environmental Policy Act (NEPA) Environmental Assessment (EA) associated with the land transfer. The evaluation includes an integrated approach for former/existing waste sites and assesses potential for impacts to the groundwater and Columbia River from proposed future uses and water use/management of the land transfer.

The proposed land use for the site is light industrial, including a solar farm. Stormwater drainage facilities will be required to manage the runoff generated from new impervious areas. Recharge at the site will be altered because 1) infiltration will cease underneath impervious areas, 2) stormwater treatment ponds will concentrate recharge at treatment pond locations, and 3) landscape irrigation will increase infiltration in green spaces. The potential mounding of groundwater due to concentrated runoff from the stormwater drainage facilities was simulated by applying TMR techniques to an existing groundwater model. The groundwater model was used to evaluate potential changes in water levels and hydraulic gradients, and is documented in a separate ECF (ECF-300FF5-17-0039, *Analysis of Potential Land Development Approaches on Recharge and Groundwater Flow near the Land Conveyance in 300 Area*).

2 Background

The Department of Energy completed a draft environmental assessment of Hanford land to be used for economic development. The Tri-City Development Council (TRIDEC), along with local governments, requested Hanford land just north of Richland for economic development. Added to that request were 300 acres proposed for a solar farm. Uranium and nitrate plumes exist under and adjacent to the southern and eastern portions of the land conveyance site; there is concern these plumes may be mobilized by a sudden increase in groundwater recharge from new stormwater ponds.

3 Methodology

The proposed land use at the land conveyance site is light industrial, the definition of which can be highly variable but typically comprises large areas of impervious pavement and roofs. To prevent flooding and provide treatment, stormwater ponds will be constructed to store excess water that is generated from rainfall on the impervious areas. The Stormwater Management Manual for Eastern Washington (WA ECY, 2004), the Washington State Department of Transportation (WSDOT) Highway Runoff Manual (WSDOT, 2014) and the Design Manual for Sizing Infiltration Ponds (Massman, 2003) were consulted for stormwater pond design guidance. The stormwater manual (WA ECY, 2004) provides a list of eight options in order of preference for the discharge of excess stormwater. The first option is to maintain dispersed sheet flow, and the second option is to infiltrate onsite. The second option is the most feasible for an industrial park. Infiltration ponds concentrate stormwater at point locations and leave more space for developable land than attempting to maintain natural sheet flow.

Three primary ways to determine the quantity of stormwater discharge to be infiltrated are (WA ECY, 2004): 1) a single-value or fixed volume of runoff water, 2) a single event, or single storm, runoff hydrograph, and 3) a continuous hydrograph that considers multiple events or storms over some longer period. The second and third options were applied in this ECF. Single event storms were used to determine infiltration pond sizing, and a continuous simulation was used to obtain infiltration volumes for the TMR model.

A number of site design approaches could be evaluated, such as 1) maximizing evaporation by constructing infiltration ponds with large surface areas, 2) maximizing developable land by reducing the number of ponds, and 3) implementing low-impact development (LID) techniques to reduce impervious surface areas and minimize the runoff from the project site. The amount of impervious area and irrigated landscape in each design will affect the infiltration rate and recharge to groundwater.

For this ECF, a highly conservative approach was developed first in order to introduce large amounts of recharge and observe the impact to groundwater elevations. This conservative approach includes the following:

1. A high percentage (85%) of the area in each basin is impervious to increase runoff volume to the ponds.
2. The delineated basins are large so that the amount of impervious area per pond is very large, which highly concentrates the stormwater at the pond locations.
3. Infiltration ponds were therefore sized to contain large amounts of runoff (using the 100-year 24-hour storm) to prevent overflow and to retain all stormwater onsite.
4. High infiltration rates, between 7.6 and 9.2 in/hr, were applied to the ponds. Infiltration values varied by depth and pond geometry.
5. The daily rainfall for the wettest year (1996) in a period of interest of 74 years was used to determine the volume of infiltration from the ponds in a continuous simulation. The total rainfall for 1996 was 13.7 inches; the average annual rainfall is 7.6 inches.
6. Ponds K, L, M, and N in the southeast corner of the study area (see Figure 3-1) are located directly over a contaminant plume.

An ArcGIS[1] shapefile of the focused study area (see Figure 3-1) was provided by Mission Support Alliance (MSA). The acreage of this area as calculated within ArcMap 10.1 is 2,462 acres. The 300-acre solar farm (hatched area in figure) was removed from the stormwater analysis since the runoff from the solar panels will not be directly connected to centralized drainage. The remaining focused study area is 2,162 acres and is over 3 miles long.

The first step of the analysis was to identify fourteen low spots in the study area that would be likely locations for stormwater treatment ponds. Next, the study area was divided into fourteen basins, with one infiltration pond located at each low point (Figure 3-1). The size of the basins determines the length, size, and associated cost of pipes and/or ditches required to connect the impervious areas to the ponds.

[1] ArcGIS is a registered trademark of ESRI, Inc., Redlands, California, in the United States and other countries.

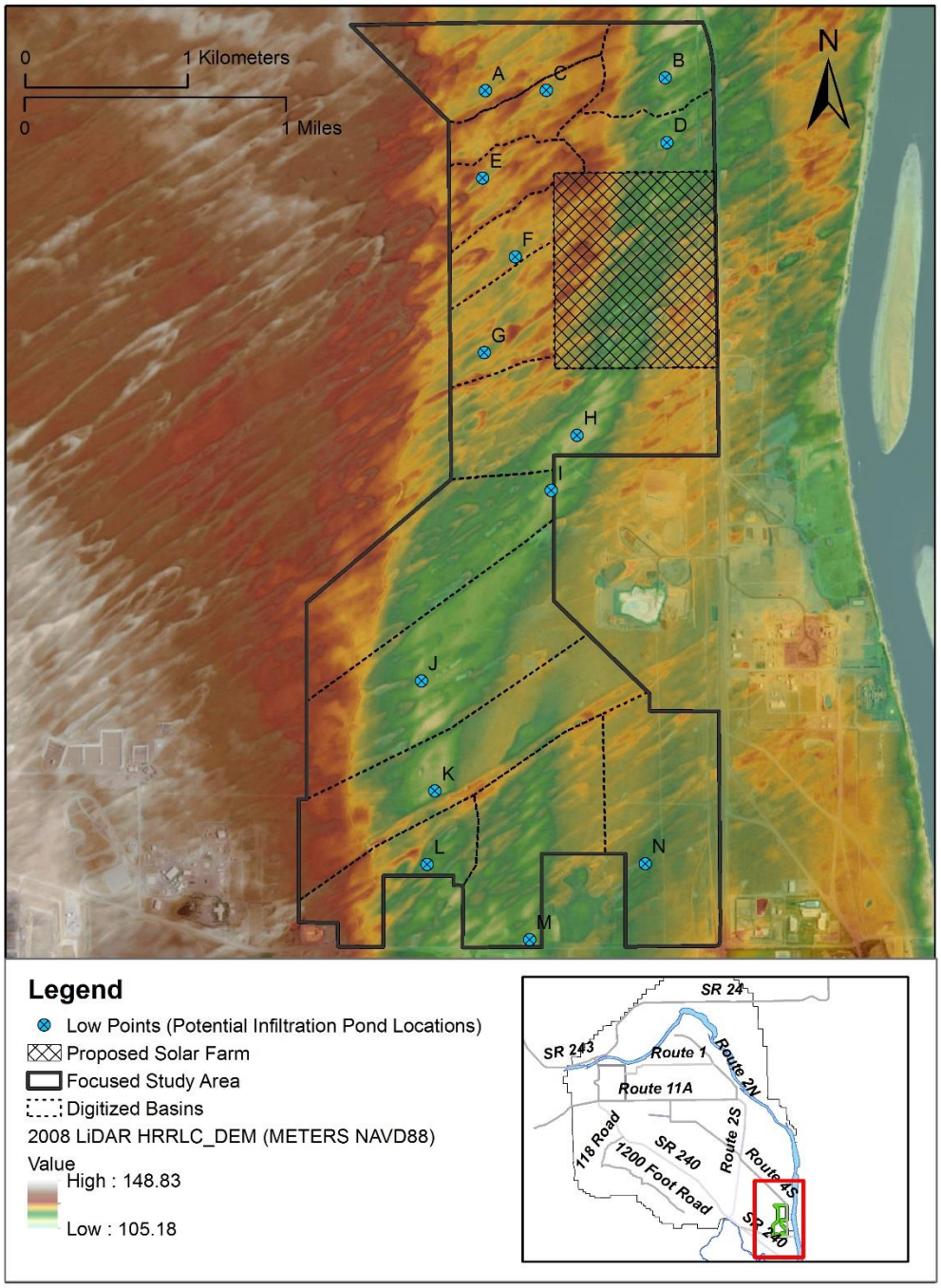

Figure 3-1. Land Conveyance Site Conceptual Basins and Ponds

WSDOT equations were applied to estimate the infiltration rate for dry ponds in the fourteen conceptual basins in order to determine very conservative (high) annual recharge rates to groundwater from the ponds. The infiltration rates as a function of depth were input into a stormwater model, and daily rainfall data from the wettest year on record were applied to obtain conservatively high infiltration volumes. The ponds were sized using the stormwater model and the following infiltration equations provided by Massman (2003).

The effective gradient under steady-state conditions beneath a medium-sized infiltration facility can be approximated by:

$$gradient = i \approx \frac{D_{wt}+D_{pond}}{138.62(K^{0.1})} CF_{size} \qquad \text{Equation 2-1}$$

Where:

K = saturated hydraulic conductivity, in feet/day

D_{wt} = depth from the base of the infiltration trench to the water table or to the first low-permeability layer, in feet

D_{pond} = depth of water in the pond, in feet

CF_{size} = correction for pond size

The correction for pond size is calculated by:

$$CF_{size} = 0.73(A_{pond})^{-0.76} \qquad \text{Equation 2-2}$$

Where:

A_{pond} = area of bottom of pond, in acres

Based on Darcy's law, the infiltration rate can be estimated by multiplying the saturated hydraulic conductivity with the hydraulic gradient:

$$f = Ki \qquad \text{Equation 2-3}$$

Where:

f = specific discharge or infiltration rate of water through a unit cross-section of the infiltration facility

K = hydraulic conductivity, in feet/day

i = gradient for ponds and trenches at sites with shallow water tables, or a value of approximately 1 for ponds and trenches at sites with deep water tables

Depending upon the level of pretreatment and the maintenance program that is put in place at the stormwater facility, the long-term infiltration rates may be reduced significantly by factors such as siltation and biofouling:

$$f_{corr} = (CF_{silt/bio})(CF_{aspect})f \qquad \text{Equation 2-4}$$

Where:

$CF_{silt/bio}$ = correction factor for siltation and biofouling

CF_{aspect} = correction factor for aspect ratio

f = "uncorrected" infiltration rate

Correction factors for siltation and biofouling are in Table 3-1. A value of 0.9 was selected for both the short-term and long-term infiltration rate calculations for this ECF.

Table 3-1. Correction Factors for Siltation and Biofouling (Massman, 2003)

Potential for biofouling	Degree of long-term maintenance and performance monitoring	Infiltration rate reduction factor	
		Ponds	Trenches
Low	Average to high	0.9	0.9
Low	Low	0.6	0.8
High	Average to high	0.5	0.75
High	Low	0.2	0.6

A correction factor is also applied for aspect ratio since ponds with large aspect ratios (defined as pond length divided by pond width) have higher infiltration rates than ponds with lower aspect ratios:

$$CF_{aspect} = 0.02A_{ratio} + 0.98 \qquad \text{Equation 2-5}$$

Where:

A_{ratio} = length/width of the pond

A Microsoft Excel®[2] spreadsheet with these infiltration equations is provided online by the WSDOT. The file *InfiltrationCalc.Spreadsheet.xls* was downloaded from www.wsdot.wa.gov on October 13, 2015 and modified for use. For example, the highway manual for Washington (WSDOT, 2016) states that an infiltration pond may be sized to a maximum depth of 6 feet, so another row was added to the original spreadsheet to allow for 6-ft deep ponds. Figure 3-2 depicts the final version of the calculation portion of the spreadsheet used for this ECF.

[2] Excel is a registered trademark of Microsoft Corporation in the United States and in other countries.

Infiltration Ponds

Spreadsheet downloaded from www.wsdot.wa.gov on 10/13/2015

Length of Pond Bottom (ft)	500	Width of Pond Bottom (ft)	225
Area of Bottom of Pond (acres)	2.58		
Pond Side Slopes (3:1 typical)	3		

Cells shaded green indicate user input

Cells shaded yellow indicate pond-specific user input

Depth of Pond, D_{pond}	Depth to Water Table, D_{wt}	Hydraulic Conductivity, K_{equiv}	Pond Top Surface Area	Hydraulic Gradient, i	CF_{size}	Infiltration Rate, f	Length of Pond	Width of Pond	CF_{aspect}	$CF_{silt/bio}$	Adjusted Infiltration Rate, f_{corr}
Varies 1' to 6'	*Source: 2008 LiDAR DEM and water table contours*	*Determined by Lab Tests*	*Determined by designer*	*Equation 2.6*	*Equation 2.7 (Max value of 1.0)*	*Equation 4-16*			*Equation 4-17 (1.4 max value)*	*See Table 4-9*	*Equation 4-18*
(ft)	(ft)	(in/hr)	(Acres)			(in/hr)	(ft)	(ft)			(in/hr)
0			2.58								
1	33	8.7	2.58	0.065	0.35	0.57	500	225	1.02	0.9	0.52
2	33	8.7	2.68	0.067	0.35	0.59	506	231	1.02	0.9	0.54
3	33	8.7	2.79	0.069	0.35	0.60	512	237	1.02	0.9	0.56
4	33	8.7	2.89	0.071	0.35	0.62	518	243	1.02	0.9	0.57
5	33	8.7	3.00	0.073	0.35	0.64	524	249	1.02	0.9	0.59
6	33	8.7	3.10	0.075	0.35	0.65	530	255	1.02	0.9	0.60

Figure 3-2. Spreadsheet Used for Pond Infiltration Equations

Using the WSDOT spreadsheet, a long-term low infiltration rate was calculated in one-foot increments to a 6-ft maximum pond depth for each of the fourteen ponds. The hydraulic gradient was calculated using Equation 2-1. Criteria for design infiltration rates in the eastern Washington stormwater manual (WA ECY, 2004) state the long-term soil infiltration rate should be a minimum of 0.5 inches per hour and a maximum of 2.4 inches per hour, to a depth of 2.5 times the maximum design flooded depth. For example, if the depth to the water table under a pond is 7.5 ft, the maximum stage in the pond for a selected design storm cannot exceed 3 ft (2.5 x 3 = 7.5 ft). The spreadsheet values for long-term infiltration rate for the fourteen ponds ranged from 0.5 to 1.97 in/hr.

A conservative estimate of infiltration in the ponds was obtained using XPSTORM 2016.1, a stormwater model that incorporates algorithms from the U.S. Environmental Protection Agency (USEPA) Stormwater Management Model (SWMM). The XPSTORM model was constructed to simulate a number of design storms specified in the stormwater guidelines for the City of Richland (CoR, 2016) and eastern Washington (WA ECY, 2004). The City of Richland guidelines were included because the land conveyance site may be annexed by the City. Iterative simulations using five design rainfall events were run to determine the size of the infiltration ponds. The ponds were designed to 1) prevent overflow during the 100-year 24-hour event using long-term (low) infiltration rates, and 2) fully infiltrate within 72 hours of the end of the water quality storm event (WA ECY, 2004).

After the pond sizes were determined, the WSDOT spreadsheet was revised for short-term (high) infiltration rates. The hydraulic gradient was changed to approximately 1 for each 1-ft increment up to the 6-ft maximum depth for each pond. This adjustment greatly increased the infiltration rates, which ranged from 7.6 to 9.2 in/hr. An XPSTORM continuous simulation was set up using these conservative short-term (high) infiltration rates for 1996, the wettest year on record, to determine the most conservative annual infiltration volume to groundwater.

In addition to the highly conservative approach, a LID scenario was simulated using similar methodology as described above. The application of permeable pavement is a LID technique that may be used in eastern Washington to reduce impervious surface areas and minimize the increase in runoff rates from a project site (WA ECY, 2004). Permeable pavement is an open-graded mix placed in a manner that results in a high degree of voids within the cemented aggregate; this allows rainfall to infiltrate through to the subsoils (WSDOT, 2016). Permeable pavement has grown in popularity for LID; however, the functionality of the permeable pavement requires continued maintenance to preserve the infiltration capacity. Permeable pavement is suitable for parking areas but is susceptible to wear in heavy traffic areas

like roads. To simulate this LID technique, each basin was divided between impervious surfaces (roads and roofs) and pervious surfaces (permeable pavement and green spaces). A nearby industrial park southeast of the conveyance site (Figure 3-3) was selected to approximate representative fractions of roofs, parking areas, green space, and roads/other impervious. Permeable pavement is permissible for parking areas (WSDOT, 2016) and was assumed for the analysis. The area of each model basin was divided into one 100% impervious subcatchment, representing the roofs and roads, and one 100% pervious subcatchment, representing the permeable parking areas and green space.

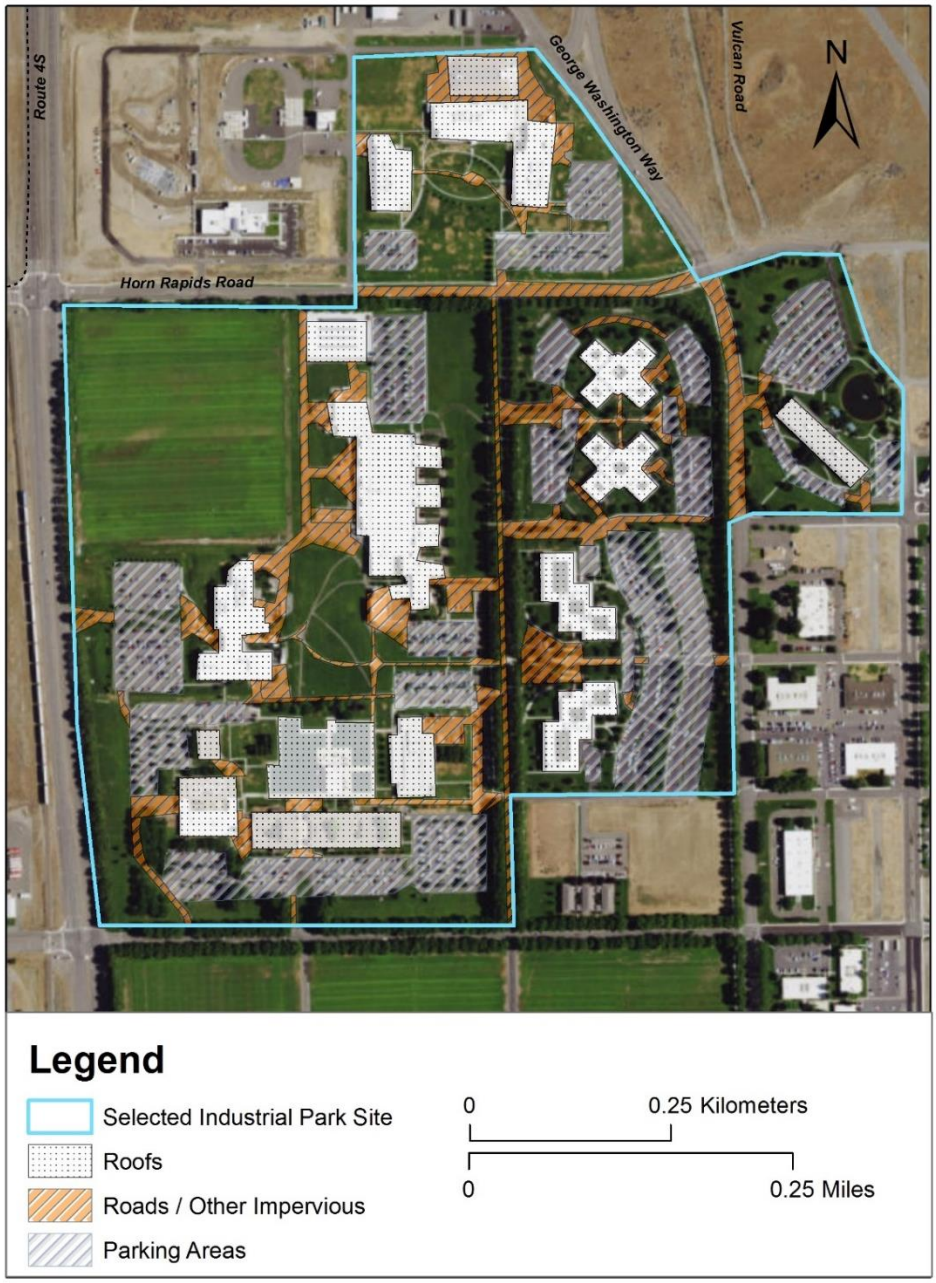

Figure 3-3. Representative Industrial Park

4 Assumptions and Inputs

The input data and assumptions for the infiltration equations and the XPSTORM models are described in this section.

4.1 Drainage Basins

A digital elevation model (*HRRLC_DEM.tif*) created from 2008 LiDAR data was obtained from INTERA's Hanford GIS database. Topographic 1-meter contours were generated using ArcMap 10.1 Spatial Analyst. The DEM and contours were used to identify fourteen low points as potential pond locations. The associated drainage area for each low point was then delineated using contours, aerial imagery, and natural breaklines such as ridges.

For the conservative approach, each of the fourteen conceptual industrial park basins was assumed to be 85% impervious. It was further assumed that all of the impervious area would be directly connected, meaning that runoff would have no opportunity to infiltrate before reaching the stormwater ponds. It was assumed the proposed solar farm will not have any directly connected impervious area and was excluded from the stormwater calculations. Table 4-1 shows the total area and impervious area of each basin. The basins have a large amount of impervious area per pond in the conservative scenario to concentrate stormwater and therefore increase infiltration. Soil Conservation Service (SCS) hydrology is required by the stormwater manual (WA ECY, 2004). A curve number of 98 was assigned to the impervious areas (WA ECY, 2004). No pervious areas were included in the conservative scenario simulation; this simplified the calculations and reduced simulation time.

Table 4-1. Basin Total Area and Impervious Area for the Conservative Scenario

Basin	Total Area (acres)	Impervious Area (acres)
A	173.4	147.4
B	90.6	77.0
C	40.2	34.1
D	83.6	71.0
E	72.8	61.8
F	58.3	49.6
G	94.6	80.4
H	237.1	201.6
I	226.7	192.7
J	297.0	252.5
K	252.5	214.6
L	103.5	87.9
M	191.3	162.6
N	241.3	205.1

For the LID approach, each of the fourteen basins was assumed to be 25% impervious area based on the percentage of roofs and roads from Figure 3-3. Table 4-2 shows the acreage of pervious area (permeable pavement and green spaces) and impervious area (roofs, roads, etc.) of each basin. The total area remained the same as in the conservative scenario.

Table 4-2. Basin Pervious and Impervious Area for the Low Impact Development Scenario

Basin	Pervious Area (acres)	Impervious Area (acres)
A	130	43.4
B	67.9	22.7
C	30.2	10.0
D	62.7	20.9
E	54.6	18.2
F	43.7	14.6
G	71.0	23.6
H	177.8	59.3
I	170.0	56.7
J	222.7	74.3
K	189.4	63.1
L	77.6	25.9
M	143.5	47.8
N	181.0	60.3

4.2 Soils

Soils information was derived from two sources: 1) a soil shapefile (*SOILSP.shp*) from the Bechtel Hanford GIS 1997 archive and 2) *Vadose Zone Hydrology Data Package for Hanford Assessments* (PNNL-14702, 2006). The soil at thirteen pond locations is classified as Quincy Sand with a hydraulic conductivity value of 100.36 micrometers per second. One pond location is situated in Burbank Loamy Sand with a hydraulic conductivity value of 100.33 micrometers per second. Both sands are classified as Type A based on the following description from the National Resources Conservation Service (2007): "*Soils that are deeper than 100 centimeters [40 inches] to a water impermeable layer are in group A if the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface exceeds 10 micrometers per second (1.42 inches per hour).*" It was assumed that the highest expected value of hydraulic conductivity at the pond locations would be 100 micrometers per second, or 14.7 inches per hour. Soil boring data is available in the vicinity of the project site in Appendix A and B of *Vadose Zone Hydrology Data Package for Hanford Assessments* (PNNL-14702, 2006). In the nearby southern 600 Area, Hanford coarse sand has a mean hydraulic conductivity value of 0.00227 centimeters per second, or 3.22 inches per hour. The average hydraulic conductivity of the two data sources, or 8.7 inches per hour (in/hr), was used in WSDOT equations for the infiltration rate.

To check the reasonableness of using 8.7 in/hr, the hydraulic conductivity values in the Tank Closure Environmental Impact Statement (EIS) groundwater model (DOE, 2005) were investigated. Vertical hydraulic conductivity values in the unsaturated zone of the project area range from 1.92 m/d (3.15 in/hr) to 398 m/d (653 in/hr). The EIS model value for vertical hydraulic conductivity of Hanford sand is 12.36 m/d (20.3 in/hr). Due to the high permeability of the sands at the project site, it was assumed that runoff from non-directly connected impervious area would completely infiltrate into the pervious area Type A soils and would not enter the ponds. Existing offsite flows were considered as well. There is a meandering shallow channel (depth appears to be 0.5 ft to 1 ft) that originates in the western portion of Basin G; it travels southwest through Basin H, exits Basin H, turns south and enters Basin I, continues south through the site, and terminates at the southern boundary of the focused study area at Horn Rapids Road. Even

though the channel exits and re-enters the study area, it was assumed that no offsite runoff would flow into the project site from the channel due to the Type A soils.

4.3 Rainfall

Five design rainfall events were selected from the stormwater management manual (WA ECY, 2004) and the City of Richland guidelines (CoR, 2016) for the conceptual pond design. The stormwater management manual classifies pond function as either flow control or water quality treatment. The total rainfall for flow control and water quality storm events for Climate Region 2 (Central Basin) in eastern Washington are summarized in Table 4-3 and Table 4-4, respectively. The average annual precipitation in this region is 6 to 8 inches per year. In addition to these storm events, the 25-year 24-hour storm event (1.6 inches of rainfall for this project area) was included since the City of Richland uses this storm for hydrologic analysis and design of privately owned and maintained commercial sites (CoR, 2016).

Table 4-3. Design Rainfall Amounts for Flow Control

Design Storm	Total Rainfall (inches)
2-year 24-hour	0.9
100-year 24-hour	1.9

Table 4-4. Design Rainfall Amounts for Water Quality Treatment

Design Storm	Total Rainfall (inches)
2-year 2-hour	0.41
2-year 24-hour	0.9
6-month 24-hour	0.59

Event-based simulations were performed in XPSTORM using the SCS Type IA rainfall distribution (WA ECY, 2004) for the five design storms. Long-term (low) infiltration rates were used for pond sizing because infiltration rates have been observed to decrease over time due to siltation and/or biofouling. The infiltration rates may be affected by site conditions, effectiveness of pretreatment or influent control, and degree of long-term maintenance of the infiltration facility (WA ECY, 2004). To avoid pond overtopping and the discharging of stormwater offsite, the 100-year 24-hour storm simulation was used to size the ponds. For water quality, the 6-month 24-hour storm simulation was checked to ensure that the ponds drain within 72 hours after the cessation of the storm (WA ECY, 2004).

Continuous simulations were performed in XPSTORM using daily rainfall data and short-term (high) infiltration rates. The rainfall station with the longest period of record near the site is the NOAA Kennewick WA US station. Daily rainfall for this station was downloaded from the National Climatic Data Center web site (https://www.ncdc.noaa.gov/cdo-web/) for dates ranging from February 1, 1894 to September 30, 2015. The period of interest was January 1, 1941 to December 31, 2014; annual rainfall for this period is shown in Figure 4-1. The wettest year on record is 1996 with 13.7 inches. The relative magnitude of this rainfall amount is corroborated in *Hanford Site Climatological Summary 2004 with Historical Data* (PNNL-15160, 2005). Three years of the Kennewick rainfall record, 1976, 1978, and 1979, have significant data gaps (missing 31, 31, and 91 days, respectively); these missing values were set to zero. The years 1996, 1998, 2001, and 2003 have 29, 30, 60, and 31 days of missing data, respectively, and were supplemented with rainfall data from the 300 Area Hanford Meteorological Station

#11. The supplemental data for 1996 were all zero values in the month of July. The processed daily rainfall record was input into XPSTORM 2016.1 for an available range of simulation time from January 1, 1941 to December 31, 2014.

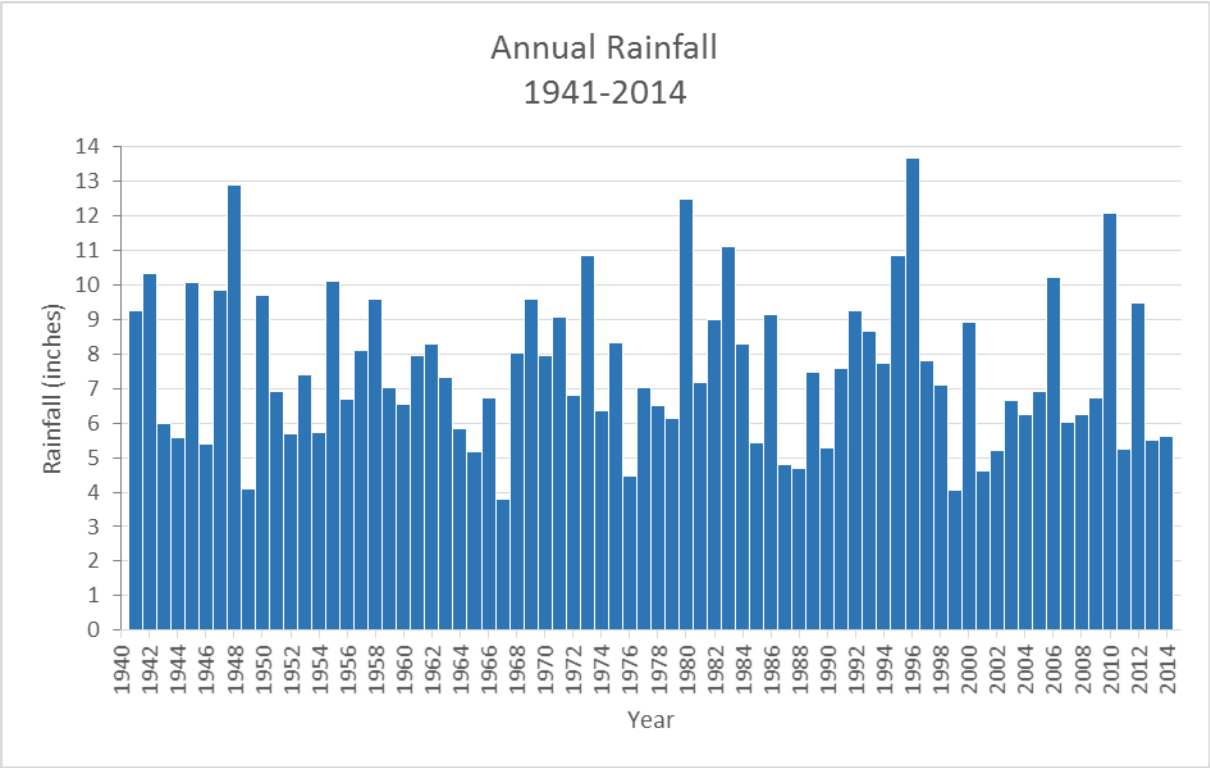

Figure 4-1. Annual Rainfall from NOAA Kennewick WA US station for 1941-2014

4.4 Evaporation

Daily pan evaporation data were downloaded from the NOAA National Climatic Data Center web site (https://www.ncdc.noaa.gov/cdo-web/) for the following stations: Connell 1 W WA US, Hermiston 1 SE OR US, Pendleton BR Experimental Station OR US, Pendleton Weather Forecast Office OR US, Prosser WA US, Quincy 1 S WA US, Yakima Air Terminal WA US. All no-data values of -9999 were removed. No data were available for January from any station, so the average December value was used. Only the Prosser station had data for the months of February and December; the period of record for this station was June 1, 1948 through October 31, 1973. All of the stations had data for April through October, though the period of record varied. The two Pendleton stations had the most recent data through 2015.

All available daily values for each station were averaged for each month beginning June 1, 1948 and ending September 30, 2015. All resulting January values were then averaged, then all February values, etc. over the period of record. Finally, a pan coefficient of 0.7 (NOAA, 1982) was applied. Each XPSTORM basin was provided with one daily evaporation value per month (see Table 4-5). The total annual evaporation used was 42.8 inches, which equals the annual free water surface evaporation at the location of the project site in the NOAA evaporation atlas (NOAA, 1982). For evaporation at the ponds, monthly integer values were required by the software and these are provided in Table 4-6.

Table 4-5. Daily Evaporation Values Used for XPSTORM Catchments

Month	Evaporation (in/day)	Month	Evaporation (in/day)
January	0.021	July	0.252
February	0.049	August	0.231
March	0.077	September	0.140
April	0.119	October	0.091
May	0.168	November	0.028
June	0.210	December	0.021

Table 4-6. Monthly Evaporation Values Used for XPSTORM Ponds

Month	Evaporation (in/month)	Month	Evaporation (in/month)
January	1	July	8
February	1	August	7
March	2	September	4
April	4	October	3
May	5	November	1
June	6	December	1

5 Software Applications

XPSTORM was the primary software used for this calculation. Microsoft Excel 2013 spreadsheets were used to calculate pond infiltration rates to be used as input for storage nodes in XPSTORM.

5.1 Approved Software

XPSTORM was selected because it fulfills the following specifications:

- The XPSTORM software can perform both event-based and continuous hydrologic and hydraulic simulations as required by Washington State stormwater guidelines.
- The XPSTORM software can simulate infiltration rate as a function of depth in ponds.
- The XPSTORM software incorporates algorithms from the United States Environmental Protection Agency Storm Water Management Model (SWMM), which is a well-established and widely applied model for stormwater calculations.
- The modeling team implementing this software is familiar with its use.
- The XPSTORM software includes a graphical user interface to assist the user with pre- and post-processing.

For more information, refer to Appendix A.

5.1.1 Description

The following describes the XPSTORM software:

Software Title: XPSTORM

Software Version: 2016.1

Hanford Information System Inventory (HISI) Identification Number: 4094

Workstation Type and Property Number: XPSTORM was executed on an INTERA Tampa Hewlett-Packard Compaq[3] Elite 8300 CMT computer. The processor is an INTEL® CORE™[4] i5-3570 CPU @ 3.40 Ghz 3.40 Ghz (2 processors) with 6.0 GB RAM running a 64-bit operating system.

5.1.2 Software Installation and Checkout

The Software Installation and Checkout form is not required because XPSTORM is graded as Level D based on intended use.

5.1.3 Statement of Valid Software Application

Appendix A contains a summary of the main model attributes that serve as the basis for the demonstration of the adequacy of XPSTORM for use in stormwater modeling at Hanford.

6 Calculation

Example calculations for Pond A are presented in this section. In an iterative process, low infiltration values were input into XPSTORM and adjusted over a number of event-based simulations until the overflow and water quality criteria for the ponds were met. Once the ponds were sized, high infiltration rates were input into XPSTORM for continuous simulation.

6.1 Infiltration Rate Equations

To size the ponds, the WSDOT equations were applied to estimate low infiltration rates as a function of depth. Low infiltration rates at 1-ft pond depth intervals from 0 ft to 6 ft were calculated using the WSDOT spreadsheet.

Using Equation 2-1, Equation 2-2, Table 6-3 and 8.7 in/hr hydraulic conductivity (see Section 4.2):

Gradient *i* for 1 ft pond depth = ((33 + 1)/(138.62(8.7*2)^0.1)) * (0.73*(2.58)^-0.76) = 0.065

Gradient *i* for 6 ft pond depth = ((33 + 6)/(138.62(8.7*2)^0.1)) * (0.73*(2.58)^-0.76) = 0.075

Using Equation 2-3:

Infiltration rate *f* for 1 ft pond depth = 8.7*0.065 = 0.57 in/hr

Infiltration rate *f* for 6 ft pond depth = 8.7*0.075 = 0.65 in/hr

Using Equation 2-4, Equation 2-5,Table 3-1 and Table 6-3:

Corrected infiltration rate for 1 ft pond depth = 0.57 * 0.9 * (0.02 * (500/225) + 0.98) = 0.52 in/hr

---

[3] Hewlett-Packard and Compaq are registered trademarks that belong to Hewlett-Packard Development Company, L.P.

[4] INTEL CORE is a trademark and brand of Intel Corporation

Corrected infiltration rate for 6 ft pond depth = 0.65 * 0.9 * (0.02 * (500/225) + 0.98) = 0.60 in/hr

The allowable minimum f_{corr} is 0.5 in/hr (WA ECY, 2004). When the calculated infiltration rates were less than 0.5 in/hr, the infiltration rates in the model were assigned to 0.5 in/hr (WA ECY, 2004). Once the ponds were sized to meet the overflow and water quality criteria, high infiltration rates were calculated by using a gradient (*i*) value of approximately 1, which is for deep water tables.

Using Equation 2-3:

Infiltration rate *f* for 1 ft pond depth = 8.7 * 0.97 = 8.4 in/hr

Infiltration rate *f* for 6 ft pond depth = 8.7 * 1.03 = 9.0 in/hr

Corrected infiltration rate for 1 ft pond depth = 8.4 * 0.9 * (0.02 * (500/225) + 0.98) = 7.7 in/hr

Corrected infiltration rate for 6 ft pond depth = 9.0 * 0.9 * (0.02 * (500/225) + 0.98) = 8.3 in/hr

These low and high infiltration rates at 1-ft intervals for the 6-ft deep ponds were used in XPSTORM to model the infiltration ponds. Low infiltration rates for all ponds in the conservative scenario are in Table 6-1 and high infiltration rates are in Table 6-2.

Table 6-1. Low (Long-Term) Infiltration Rates for Ponds for Conservative Scenario (in/hr)

Pond Depth (ft)	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	0.52	0.50	1.79	0.57	1.05	1.61	0.83	0.50	0.50	0.50	0.50	0.50	0.50	0.50
2	0.54	0.50	1.82	0.60	1.08	1.65	0.86	0.50	0.50	0.50	0.50	0.50	0.50	0.50
3	0.56	0.50	1.86	0.63	1.11	1.69	0.88	0.50	0.50	0.50	0.50	0.50	0.50	0.50
4	0.57	0.50	1.89	0.65	1.14	1.73	0.91	0.50	0.50	0.50	0.50	0.50	0.50	0.50
5	0.59	0.50	1.93	0.68	1.17	1.77	0.93	0.50	0.50	0.50	0.50	0.50	0.50	0.50
6	0.60	0.53	1.97	0.71	1.20	1.81	0.96	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Table 6-2. High (Short-Term) Infiltration Rates for Ponds for Conservative Scenario (in/hr)

Pond Depth (ft)	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	7.78	9.06	8.20	7.80	7.75	7.90	7.67	8.05	7.70	7.88	7.75	7.66	7.63	7.66
2	7.94	9.14	8.32	7.95	7.90	8.04	7.83	8.20	7.85	8.03	7.90	7.82	7.79	7.82
3	8.01	9.14	8.35	8.02	7.98	8.11	7.90	8.27	7.93	8.11	7.98	7.89	7.87	7.89
4	8.09	9.14	8.39	8.10	8.05	8.18	7.98	8.34	8.01	8.19	8.06	7.97	7.95	7.97
5	8.16	9.16	8.44	8.17	8.12	8.24	8.06	8.41	8.09	8.26	8.14	8.05	8.02	8.05
6	8.24	9.18	8.50	8.24	8.20	8.31	8.14	8.49	8.16	8.34	8.21	8.13	8.10	8.13

6.2 Event-Based Simulations

The XPSTORM model was set up for the conservative scenario with the following example input for Basin A and Pond A. The other basins and ponds were set up in a similar fashion. The area of Basin A in the focused study area is 173.4 acres. The impervious area of Basin A, assuming 85% paved, is 173.4 * 0.85 = 147.4 acres. The routing method within XPSTORM was set to SCS Hydrology. A curve number of 50 was assigned to the pervious areas for shrub/scrub bunchgrass mosaic with depth to water greater than 10 ft. This curve number was ignored by the model since only the impervious area of each basin was being simulated. Times of concentration for each basin were calculated using the TR-55 method available in XPSTORM. A shape factor of 484 was selected.

The ponds were represented as storage nodes, and the storage node infiltration option was enabled. The low infiltration rates from Table 6-1 were input into the storage node data dialog. All five design storms discussed in Section 4.3 were run in one simulation. The pond length and width were iteratively adjusted until no overflow occurred during the 100-year 24-hour event and the water quality volume was fully infiltrated within 72 hours of the end of the 6-month 24-hour storm event. For example, Pond A stage is shown in Figure 6-1 for the flow control and water quality treatment design storm events from Table 4-3 and Table 4-4, as well as for the City of Richland 25-year 24-hour event. The bottom of Pond A is at elevation 390 ft NAVD 88. The depth of water in the pond does not exceed 6 feet for the 100-year 24-hour event (black line labeled Flow Control Max). The red line is the 6-month 24-hour water quality volume event and infiltrates in much less time than 72 hours after cessation of the storm. The model was run until these criteria were met for all ponds. The final size and geometry for all ponds for the conservative scenario are presented in Table 6-3. Note that the estimated depths to the water table beneath the bottom of ponds J, K and L (which are 6 ft deep) are relatively shallow and may not be suitable for infiltration (WA ECY, 2004). All ponds are conceptual for this analysis; field testing at each pond location will be required to determine actual depth to water and infiltration rates.

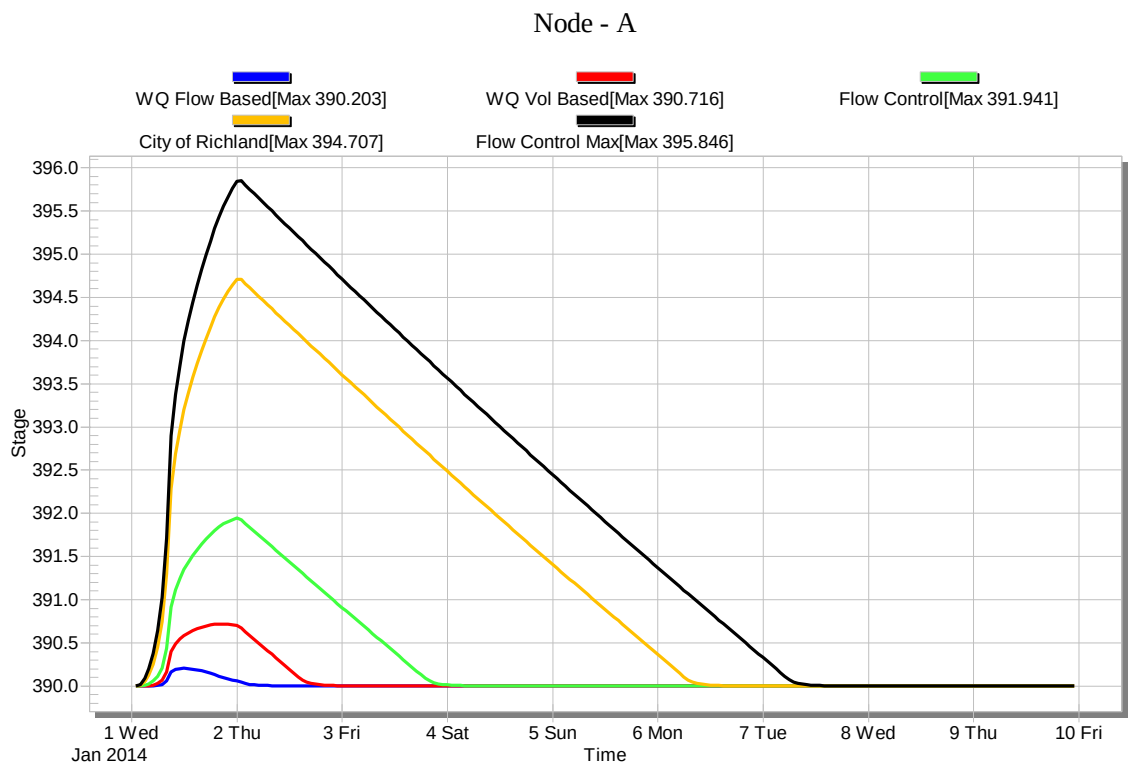

Figure 6-1. Pond A Stage for Five Design Storms Using Low Infiltration Rates

Table 6-3. Pond Size and Geometry for Conservative Scenario

Pond	Length (ft)	Width (ft)	Bottom Area (acres)	Depth to Water (ft)
A	500	225	2.58	33
B	800	75	1.38	13
C	300	60	0.41	38
D	350	150	1.21	19.7
E	300	150	1.03	33
F	300	100	0.69	36.7
G	300	200	1.38	33
H	800	200	3.67	19.7
I	500	300	3.44	20.6
J	1000	350	8.03	7.5
K	800	400	7.35	7.8
L	425	300	2.93	8.9
M	500	400	4.59	10.8
N	500	350	4.02	25.3

6.3 Continuous Simulation

Rainfall and evaporation were input into XPSTORM as described in Section 4.0. The routing method within XPSTORM was set to SWMM Runoff since this is most suitable for a continuous simulation. Non-pond pervious area infiltration was set to zero since only impervious areas were simulated. The ponds were represented as storage nodes in the same fashion as the event-based simulations, except the low pond infiltration rates were replaced with high infiltration rates from Table 6-2. The simulation period was January 1, 1995 to January 4, 1997; the ending date was selected to avoid terminating the simulation in the middle of a storm event. The years 1995 and 1996 were bracketed because 1996 was the wettest year on record and 1995 was also very wet. The simulation period was limited to these two years to reduce model run time and output file size. The simulation time step was 60 seconds and the infiltration output was hourly.

Infiltration over time for Pond A is depicted in Figure 6-3. The hourly infiltration volumes for all ponds were exported from the model and summed for 1996 to determine the highly conservative annual infiltration volume. These conservative volumes are presented in Table 6-4 and were distributed at each pond location in the TMR groundwater model. Additionally, a second pond configuration was developed for basins A, J, K, L and M to reduce the local impact to the groundwater heads by distributing the basin infiltration volumes over more ponds (see Figure 6-2). The groundwater model results for both the original and scattered pond configurations are documented in a separate ECF (ECF-300FF5-17-0039, *Analysis of Potential Land Development Approaches on Recharge and Groundwater Flow near the Land Conveyance in 300 Area*).

6.4 Low Impact Development Simulation

Both the event-based and continuous XPSTORM models were adjusted for LID by dividing the basin areas into impervious and pervious subcatchments. The impervious area accounted for 25% of the total area of each basin. The area of Basin A in the focused study area is 173.4 acres. The impervious area of Basin A, assuming 25% paved, is 173.4 * 0.25 = 43.4 acres. The pervious area, which includes permeable pavement, is 173.4 – 43.4 = 130 acres. A curve number of 50 was assigned to the pervious areas for shrub/scrub bunchgrass mosaic with depth to water greater than 10 ft. Times of concentration for each basin were calculated using the TR-55 method available in XPSTORM. The impervious areas were assigned lower times of concentration than the pervious areas. A shape factor of 484 was selected.

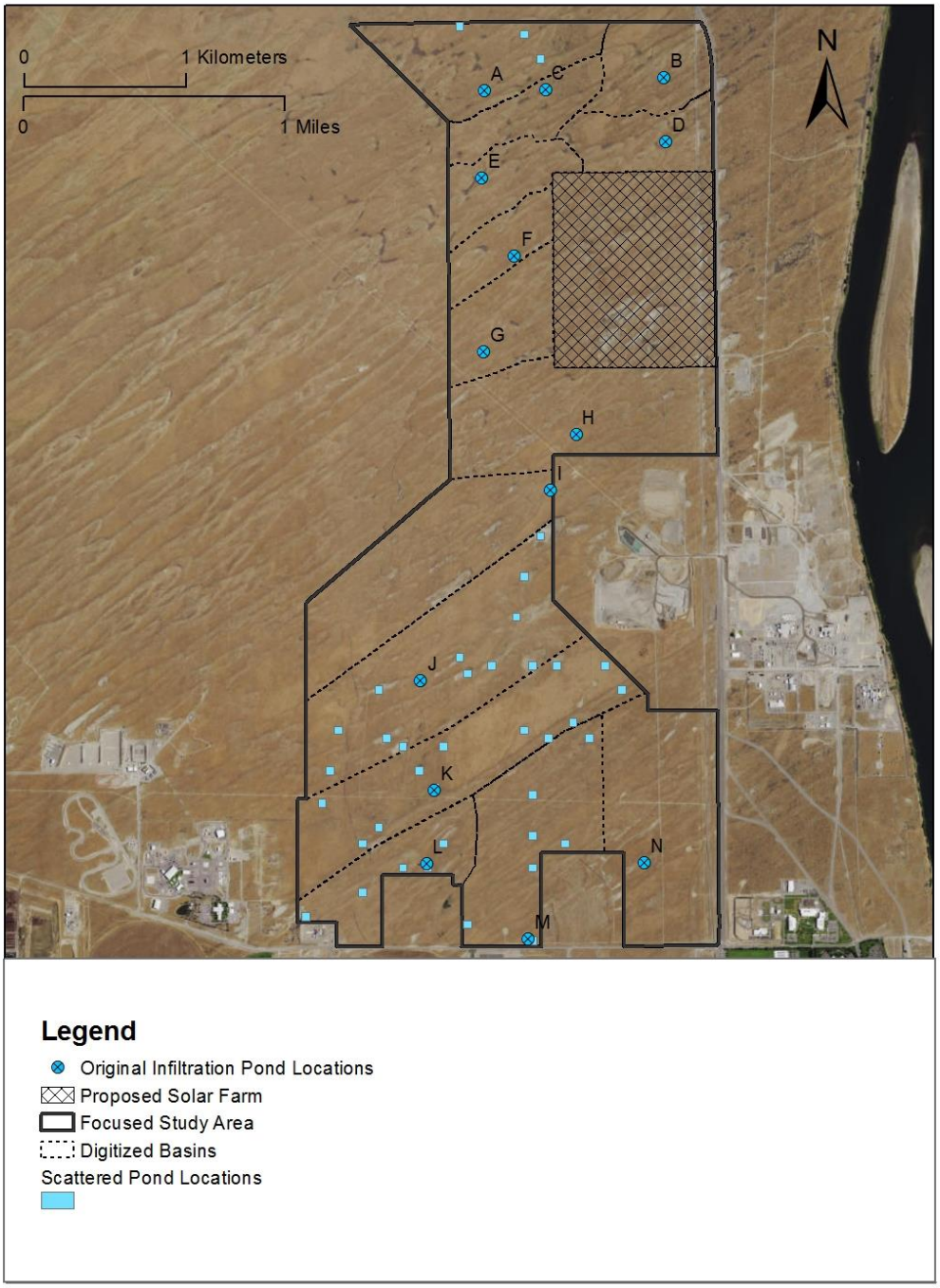

Figure 6-2. Original and Scattered Pond Distribution for Conservative Scenario

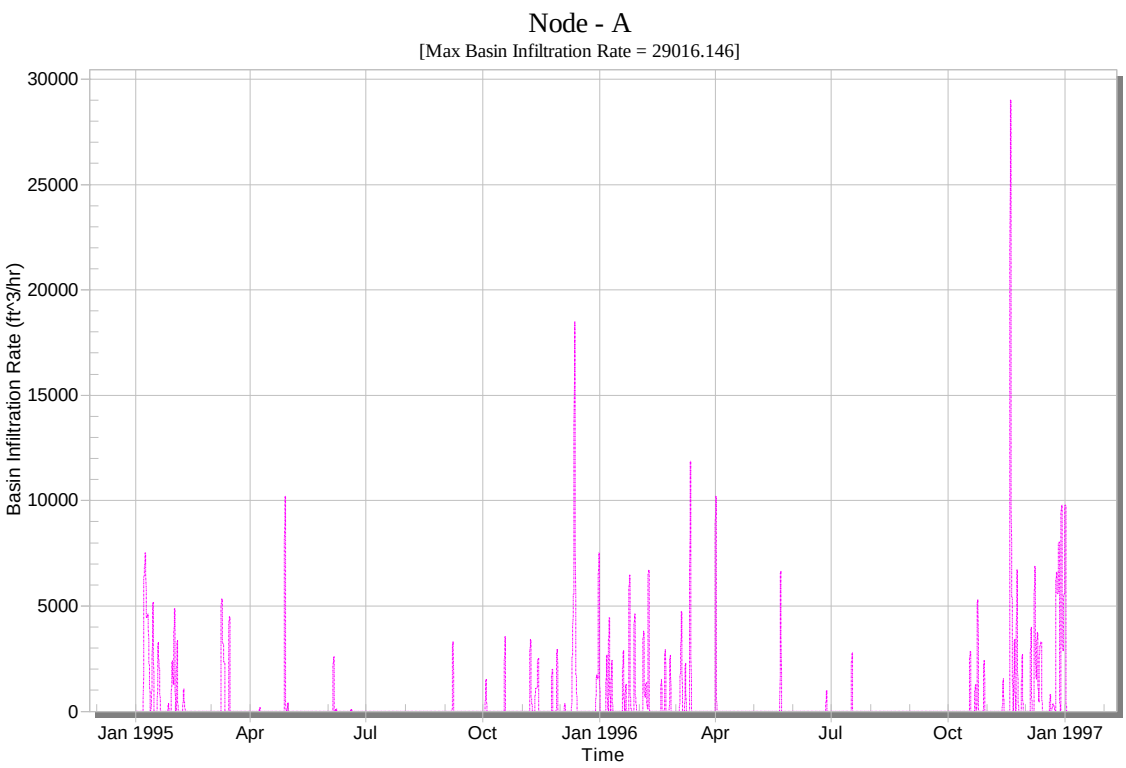

Figure 6-3. Pond A Infiltration for the Conservative Scenario

Table 6-4. Total Annual Infiltration for Conservative Scenario (1996)

Pond	Volume (ft^3)	Depth (ft)
A	4,766,594	42.4
B	2,561,920	42.7
C	1,135,046	63.1
D	2,339,816	44.6
E	2,013,094	44.7
F	1,639,962	54.7
G	2,681,396	44.7
H	6,558,830	41.0
I	6,269,026	41.8
J	8,139,204	23.3
K	6,913,967	21.6
L	2,828,361	22.2
M	5,219,440	26.1
N	6,623,524	37.8

The infiltration ponds were resized for the lower runoff volume for the LID scenario using the same methodology described in Section 6.2. Table 6-5 displays the pond geometry and Table 6-6 shows the long-term (low) infiltration rates.

The continuous simulation was performed similarly to the one described in Section 6.3. Horton infiltration was selected for the pervious area infiltration method. The ponds were represented as storage nodes in the same fashion as the event-based simulations, except the low pond infiltration rates from Table 6-6 were replaced with high infiltration rates from Table 6-7. The simulation period was the same as for the conservative scenario. The simulation time step was 60 seconds and the infiltration output was hourly.

Infiltration over time for Pond A is depicted in Figure 6-4. The hourly infiltration volumes for all ponds were exported from the model and summed for 1996. The volumes presented in Table 6-8 were distributed to the ponds in the TMR groundwater model using two configurations. The first configuration used the original pond sizes from the conservative scenario as shown in Table 6-3, and the second configuration used the reduced pond sizes in Table 6-5. The groundwater model results for both the original and reduced pond size configurations are documented in a separate ECF (ECF-300FF5-17-0039, *Analysis of Potential Land Development Approaches on Recharge and Groundwater Flow near the Land Conveyance in 300 Area*).

Table 6-5. Pond Size and Geometry for Low Impact Development Scenario

Pond	Length (ft)	Width (ft)	Bottom Area (acres)	Depth to Water (ft)
A	200	150	0.69	33
B	200	100	0.46	13
C	100	60	0.14	38
D	150	100	0.34	19.7
E	100	100	0.23	33
F	100	100	0.23	36.7
G	150	100	0.34	33
H	250	200	1.15	19.7
I	250	200	1.15	20.6
J	300	250	1.72	7.5
K	250	250	1.43	7.8
L	150	150	0.52	8.9
M	200	200	0.92	10.8
N	250	200	1.15	25.3

Table 6-6. Low (Long-Term) Infiltration Rates for Ponds for Low Impact Development Scenario (in/hr)

Pond Depth (ft)	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	1.41	0.61	1.68	0.89	1.44	1.60	1.46	0.58	0.61	0.50	0.50	0.50	0.50	0.74
2	1.45	0.65	1.72	0.93	1.49	1.64	1.50	0.61	0.63	0.50	0.50	0.50	0.50	0.77
3	1.49	0.69	1.76	0.97	1.53	1.69	1.54	0.64	0.66	0.50	0.50	0.51	0.50	0.79
4	1.53	0.73	1.80	1.01	1.57	1.73	1.58	0.66	0.69	0.50	0.50	0.55	0.50	0.82
5	1.57	0.78	1.84	1.06	1.61	1.77	1.63	0.69	0.72	0.50	0.50	0.59	0.52	0.85
6	1.61	0.82	1.88	1.10	1.66	1.81	1.67	0.72	0.75	0.50	0.50	0.63	0.56	0.88

Table 6-7. High (Short-Term) Infiltration Rates for Ponds for Low Impact Development Scenario (in/hr)

Pond Depth (ft)	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	7.65	7.75	7.70	7.67	7.60	7.60	7.67	7.63	7.63	7.63	7.60	7.60	7.60	7.63
2	7.80	7.90	7.85	7.82	7.75	7.75	7.82	7.79	7.79	7.78	7.75	7.75	7.75	7.79
3	7.88	7.97	7.92	7.90	7.83	7.83	7.90	7.87	7.87	7.86	7.83	7.83	7.83	7.87
4	7.96	8.04	7.99	7.98	7.91	7.91	7.98	7.94	7.94	7.94	7.91	7.91	7.91	7.94
5	8.03	8.12	8.06	8.05	7.99	7.99	8.05	8.02	8.02	8.02	7.99	7.99	7.99	8.02
6	8.11	8.19	8.14	8.13	8.06	8.06	8.13	8.10	8.10	8.09	8.06	8.06	8.06	8.10

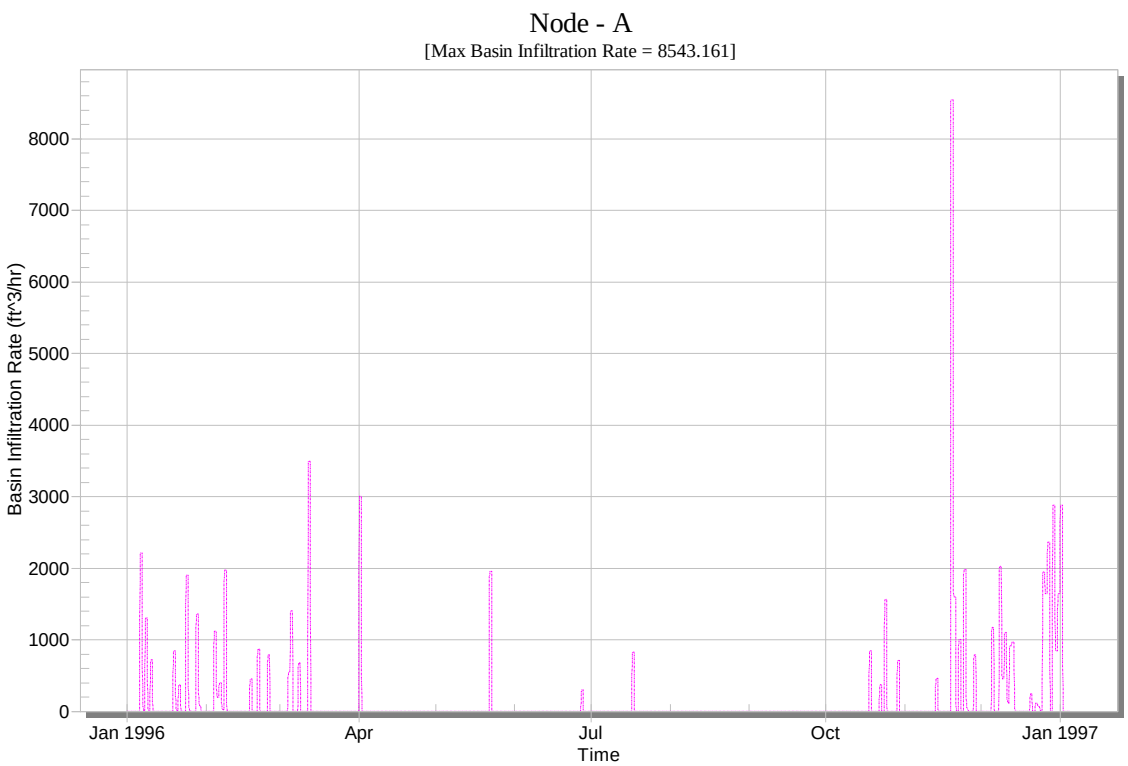

Figure 6-4. Pond A Infiltration for the Low Impact Development Scenario

Table 6-8. Total Annual Infiltration for Low Impact Development Scenario (1996)

Pond	Volume (ft^3)	Depth (ft)
A	1,473,088	49.1
B	781,231	39.1
C	344,510	57.4
D	716,312	47.8
E	620,639	62.1
F	501,055	50.1
G	817,941	54.5
H	2,017,087	40.3
I	1,927,902	38.6
J	2,519,049	33.6
K	2,140,425	34.2
L	878,491	39.0
M	1,618,169	40.5
N	2,044,034	40.9

7 Results/Conclusions

Infiltration rates for fourteen conceptual stormwater ponds were estimated as a function of pond depth and used as input for event-based and continuous simulations. A stormwater model was applied to 1) size the ponds using design storms and 2) calculate the infiltration volume at each pond on an hourly basis for one year. The selected year, 1996, is the wettest year of the rainfall record (as of early 2017). The infiltration volumes for the wettest year resulted in conservative recharge values for the TMR of an existing groundwater model. The results of the TMR groundwater model are documented in an accompanying ECF (ECF-300FF5-17-0039, *Analysis of Potential Land Development Approaches on Recharge and Groundwater Flow near the Land Conveyance in 300 Area*).

8 References

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Appendix A

Introduction to XPSTORM and SWMM

Introduction to XPSTORM and SWMM

This appendix provides a brief description of the stormwater model and underlying theory used for this ECF.

XPSTORM DESCRIPTION

The following are excerpts from the web site:
http://xpsolutions.com/Software/XPSTORM/

> *XPSTORM is a versatile software package for dynamic modeling of urban stormwater systems, river systems and floodplains including ponds, rivers, lakes and interaction with groundwater. This combined 1D (for upstream to downstream flow) and 2D (for flow over land) software is widely used by private consultants and public agencies responsible for stormwater and flooding regulation.*
>
> *XPSTORM is one of the most stable and well-accepted modeling and design packages in the world. It has been tested and approved for use by the U.S. EPA for National Flood Insurance Program submissions and was rigorously tested by the U.K. Environment Agency with excellent results.*

The following are excerpts from the technical description document:
http://xpsolutions.com/assets/dms/xpstorm-techdesc.pdf

> *XPSTORM is a package for planning, modeling and managing sustainable drainage systems. It simulates stormwater and river flows including treatment in typical LID (WSUD) systems. Hydraulically, flows are simulated in 1D channels and pipes and coupled to a 2D surface grid for comprehensive flood modeling and mapping. The software is used by scientists, engineers as well as resource and asset managers to simulate natural rainfall-runoff processes and the performance of engineered systems that manage our water resources.*
>
> *XPSTORM is used to develop link-node and spatially distributed models that are used for the analysis, design and simulation of storm collection and conveyance systems. XPSTORM also models flow in natural systems including rivers, lakes, floodplains with groundwater interaction and with the Water Quality module also routes pollutants and treatment through these systems.*
>
> *Rainfall*
>
> *Users may select either design storms or actual recorded rainfall events. Rainfall hyetographs may be linked to a model using off line files or assigned from a global list to catchments. Continuous simulation can be used to evaluate Hydromodification and model catchment response to long-term rainfall records while including multiple rainfall stations.*
>
> *Design storms for any duration and return period may be created from a library of rainfall patterns that includes SCS Types I, IA, II, Florida Modified, III, B.*

Runoff

There are numerous methods available for computing storm runoff hydrographs for event or continuous simulations. These include Non-linear Runoff Routing (US EPA Runoff Method) and SCS Unit Hydrographs using a Curve Number with curvilinear or triangular unit hydrographs.

The primary runoff hydrograph generation method is the EPA SWMM non-linear runoff method. Overland flow hydrographs are generated by a routing procedure using Manning's equation and a lumped continuity equation. Surface roughness and depression storage for pervious and impervious area parameters further describe the catchment. The subcatchment width parameter is related to the collection length of overland flow and is easily calculated based on watershed characteristics. Urban, suburban, and rural areas of any size may be simulated using non-linear reservoir routing. The unit hydrograph methods such as SCS, SBUH, LA County Modified Rational, etc. are primarily used for single event simulations. The SWMM runoff method is a deterministic hydrologic method suitable for comprehensive analysis and design including the simulation of LID (WSUD) using catchment surface redirection capabilities.

BMP Analysis

Best Management Practices (BMP's) or Low Impact Development (LID) strategies may be simulated using the above procedures in XPSTORM. The model will quantify the effect of the treatment technology in terms of reduced flow (peak or total volume) and contaminant load.

Typical BMP and LID strategies simulated by XPSTORM include:

- *rain gardens*
- *dry detention basins*
- *green roofs*
- *wet ponds*
- *rain barrels*
- *swales*
- *street sweeping*
- *porous pavement*
- *infiltration trenches*
- *filter strips*

SWMM DEVELOPMENT

The following are excerpts from the web site:
http://help.xpsolutions.com/display/xps2016/SWMM+Theory#SWMMTheory-ChangesfromSWMMVersion4toXPSWMM

SWMM (Storm Water Management Model) simulates real storm events on the basis of rainfall (hyetograph) and other meteorological inputs and systems (characterization, catchment, conveyance, storage/treatment) to predict outcomes in the form of quantity and quality values. Since study objectives may be directed toward both complete temporal and spatial detail as well as to gross effects such as total pounds of pollutant discharged in a given storm, it is essential to have both time series output, i.e., hydrographs and "pollutographs" (concentrations versus time) and daily, monthly, annual and total simulation summaries available for review.

Origin and Historical Developments

Under the sponsorship of the Environmental Protection Agency, a consortium of contractors — Metcalf and Eddy, Incorporated, the University of Florida, and Water Resources Engineers, Incorporated — developed, in 1969-71, the Storm Water Management Model, SWMM, capable of representing urban stormwater runoff and combined sewer overflow phenomena. Both quantity and quality problems and control options may be investigated with the model, with associated cost estimates available for storage and/or treatment controls. Effectiveness can be evaluated by inspection of hydrographs, pollutographs, pollutant loads, and modelled changes in receiving water quality.

The original project report is divided into four volumes. Volume I, the "Final Report" (Metcalf and Eddy et al., 1971a), contains the background, justifications, judgments, and assumptions used in the model development. It further includes descriptions of unsuccessful modelling techniques that were attempted and recommendations for forms of user teams to implement systems analysis techniques most effectively. Although many modifications and improvements have since been added to SWMM, the material in Volume I still accurately describes much of the theory behind updated versions. Documentation of some of the procedures included in the 1975 Version II (Huber et al., 1975) release of SWMM is also provided by Heaney et al. (1975).

Volume II, "Verification and Testing," (Metcalf and Eddy et al., 1971b), describes the methods and results of the application of the original model to four urban catchments.

Volume III, the "User's Manual" (Metcalf and Eddy et al., 1971c) contains program descriptions, flow charts, instructions on data preparation and program usage, and test examples. This was updated in 1975 by the Version II User's Manual (Huber et al., 1971) and in 1981 by the Version 3 User's Manuals (Huber et al., 1981; Roesner et al., 1981). This present report supersedes all of these previous documents.

Volume IV, "Program Listing" (Metcalf and Eddy et al., 1971d), lists the entire original program and Job Control Language (JCL) as used in the demonstration runs. Since many routines in the updated version are similar or identical to the original, it is still a useful reference, but on the whole should be disregarded since the present coding is, in most cases, completely different.

An extensive bilbiography of SWMM usage is available (Huber et al., 1985) and is highly recommended for new users. Case studies mentioned in the bibliography are especially useful.

EXTRAN the program had its origin in the early 1960's as a model of San Francisco Bay [Shubinski, 1965]. Its early mode was a link-node receiving water model. In the early development of EXTRAN, a constant velocity approach was used, but this was later found to produce highly unstable solutions. Additional capability was added in the early 1970's to simulate the upland areas contributing stormwater runoff to San Francisco Bay.

This new model called EXTRAN was developed for the City of San Francisco in 1973 (Shubinski and Roesner, 1973; Kibler et al., 1975). At that time it was called the San Francisco Model and (more properly) the WRE Transport Model. Water Resources Engineers became wholly integrated into Camp Dresser & McKee, Inc. in 1980. In 1974, EPA acquired this model and incorporated it into the SWMM package, calling it the Extended Transport Model - EXTRAN - to distinguish it from the Transport Block developed by the University of Florida as part of the original SWMM package.

Another big increase in the model capabilities occurred in the middle 1980's when CDM undertook the simulation of Virginia Beach, Virginia, U.S.A., an area with multiple tidal bays and flat areas. The ability to model natural channels with arbitrary cross sections, variable storage areas (i.e., lakes and detention ponds) and multiple tidal boundaries was added to the EXTRAN Model by CDM in the middle 1980's.

Since the release of EXTRAN 2, the model has been refined, particularly in the way the flow routing is performed under surcharge conditions. EXTRAN 2 used surge tanks to model surcharged flow. EXTRAN 3 used an iterative solution to model surcharged flow based on a point junction formulation. EXTRAN 4 added a "Preissmann" slot to model surcharged flow as open channel flow. Most importantly in the 1980's, especially after the release of EXTRAN 4 in 1988, much experience has been gained in the use and misuse of the model by practicing engineers.

A Description of SWMM

In simplest terms, SWMM is constructed in the form of "blocks" as follows:

1.The input sources: The Runoff Block generates surface and subsurface runoff based on arbitrary rainfall (and/or snowmelt) hyetographs, antecedent conditions, land use, and topography. Dry-weather flow and infiltration into the sewer system may be optionally generated using the Transport Block.

2.The central cores: The Runoff, Transport and Extended Transport (Extran) Blocks route flows and pollutants through the sewer or drainage system (Pollutant routing is not currently available in the Extran Block). Very sophisticated hydraulic routing may be performed with Extran.

3.The correctional devices: The Storage/Treatment Block characterizes the effects of control devices upon flow and quality. Elementary cost computations are also made.

4.The effect (receiving waters): SWMM does not include a receiving water model. The Receiving Water Block (Receive) is no longer included within the SWMM framework. However, a linkage is provided for the EPA WASP and DYNHYD models (Ambrose et al., 1986).

Quality constituents for simulation may be arbitrarily chosen for any of the blocks. The Extran Block is the only block that does not simulate water quality.

The Transport, Extran and Storage/Treatment Blocks may all use input and provide output to any block, including themselves. The Runoff Block uses input from no other computational block but may receive input from Rain and Temp Blocks for meteorological input. Within XP these "blocks"

have been merged to the Runoff, Sanitary and Hydraulics modes. Some of the time series processing "blocks" now find themselves in the Utilities accessed from the Tools menu.

Changes from SWMM Version 4 to XPSWMM

Many enhancements to SWMM have been accomplished since SWMM 4.0 was released in 1989 (Huber et al., 1989, Roesner et al., 1989). The majority of these changes have been accomplished in 1992/1993 by WP Software Pty Ltd. These include:

1.Several hundred bug fixes to the original SWMM code.

2.Vertically differentiated roughness in closed and open channels. Each conduit has two regions of roughness; a higher roughness when the depth is less than a predefined depth and normal roughness from the predefined depth to the crown of the conduit.

3.Shock losses from the transition from subcritical to supercritical flow.

4.The approach velocity in the side flow weir equations is now accounted for in the program.

5.Two EXTRAN simulations can be linked via a stage boundary condition. The time history of stage and flow is connected to the stage and flow history of a previous EXTRAN simulation. EXTRAN now has the ability to interface with EXTRAN.

6.The transition between open channel flow to pressure flow at weirs has been modified to enhance the stability of the solution.

7.A demand curve for outfalls, or a Q(t) boundary condition.

8.Natural channels have automatically defined "floodplains" to account for flows above the maximum channel depth.

9.Ponded flood water at EXTRAN nodes may optionally be returned to the main system.

10.The connection between closed conduits and open conduits has enhanced stability because of adjustments to junction ground elevations.

11.Greatly enhanced stability in the EXTRAN solution of conduit flows and junction depths.

12.Expansion/contraction losses due to changes in cross sectional area are simulated in conduits.

13.Entrance/exit losses at junctions are simulated in conduits.

14.The depth at an outfall is calculated one of three ways:

> *a.Outfall depth is fixed at the normal depth. This applies especially to natural channels.*
>
> *b.Outfall depth is fixed at the critical depth.*
>
> *c.Outfall depth is the minimum of the normal depth or the critical depth based on the conduit flow.*

15.Rating curve boundary conditions for outfall, or a Q(h) boundary condition.

16.Irregular shaped closed conduits.

17.EXTRAN generates a better error analysis and continuity check.

18.Water quality in EXTRAN has begun to be implemented.

19.User defined weir exponents.

20.Transition to equivalent conduits when a weir surcharge was modified for increased stability.

21.User defined weir lengths as a function of depth.

22.User defined rating curves for weir flows.

23.One solution was implemented as the solution in XP-SWMM. It is an amalgam of the previous solutions in EXTRAN 4. The multiplicity of solutions affected program maintenance, and the surcharge iterations used for the first two solutions were the biggest cause of slow execution times in EXTRAN. The existing Version 4 solutions have been retained to provide compatibility with existing calibrated models.

24.The number of pollutants has been increased to 20 for all modules.

25.All modules can route all pollutants.

26.Number of landuses has been increased to 10 for all modules.

27.The Storage/Treatment module has been integrated into Transport allowing multiple STP's and BMP's within the one network.

28.STP's and BMP's are no longer constrained to the outlet of the system.

29.Utilities (Rainfall, Temperature, Wind, Statistics, etc.) are incorporated within the overall interface.

30.The number of hydraulic elements has been increased to 26 for all modules.

31.Weirs, Pumps and Orifices are consistent across all modules.

32.Infiltration method and parameters are now catchment dependent.

33.Rainfall Gauges may start at different times and include an optional multiplier.

34.Pollutant characteristics are local.

35.Flow divides now have explicitly defined flow paths.

36.Process (point-source) and constant flow are allowed for each pollutant.

37.Sophisticated user-defined equations are available for pollutant removal.

38.Time units are more flexible.

39.All modules can route flows through all conduit types.

40.The SCS method of hydrograph generation is now provided.

41.An EMC (Event Mean Concentration) method is now available for pollutant generation.

Upgrades

XP Solutions is continuously adding new features and upgrading XPSWMM and XPSTORM. Users with active licenses are encouraged to upgrade to the latest version.