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Modeling Subsurface Storm and Tile Drain Systems in GSSHA with SUPERLINK

Charles W. Downer, Nawa Raj Pradhan, and Aaron R. Byrd   September 2014
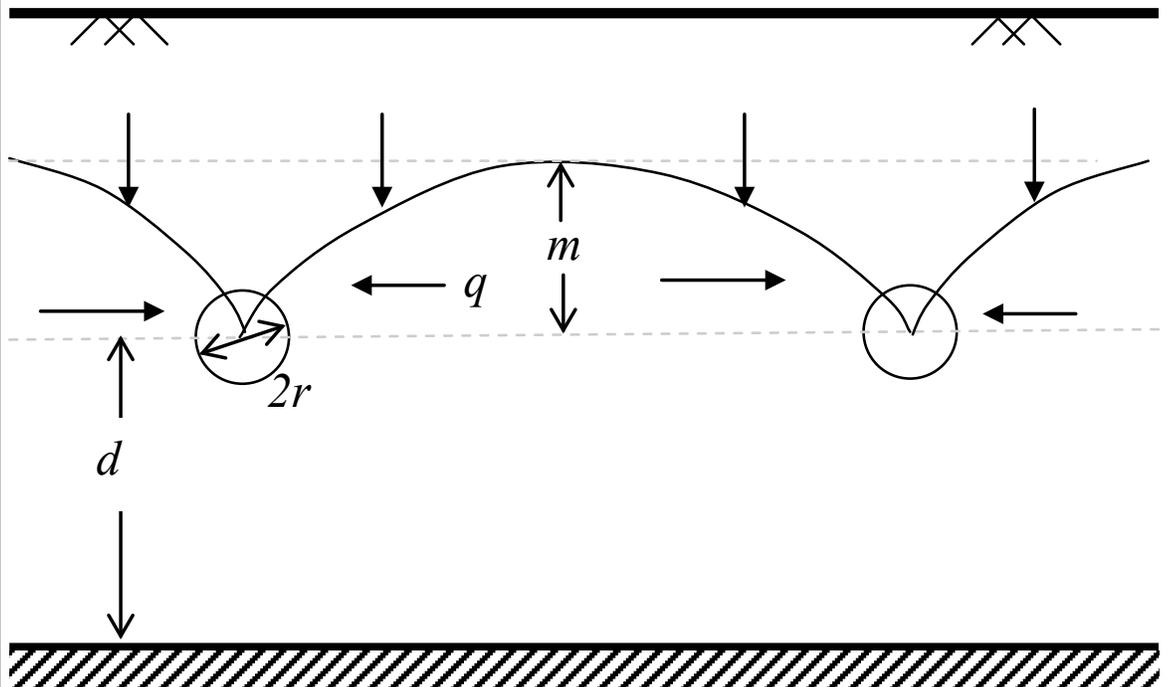
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Modeling Subsurface Storm and Tile Drain Systems in GSSHA with SUPERLINK

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Final report

Abstract

The U.S. Army Corps of Engineers Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model is a physics-based, fully distributed, hydrologic model used for hydrologic and watershed analysis. The GSSHA model can operate on individual events or continuously with calculated evapotranspiration and soil-moisture accounting between rainfall events. GSSHA is applicable to a wide range of engineering and environmental problems, such as flooding, flood control, erosion and erosion control, and total maximum daily loadings and pollution abatement. A subsurface storm drain model, called SUPERLINK, has been incorporated into GSSHA to allow the model to explicitly include the effects of subsurface drainage networks. Representing subsurface drainage networks as channel flow, overland flow, or within the groundwater parameters can lead to significant errors when simulating watersheds with subsurface drainage features. In SUPERLINK, as implemented in GSSHA, flow to the subsurface system can originate from surface openings or subsurface tile drains. In agricultural settings, tile drains are used to lower the local water table below the crop root depth and exert a dominate influence on hydrology. This document briefly describes the SUPERLINK model and the inputs for a GSSHA model with SUPERLINK in detail.

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Preface

This report describes the methods and inputs for simulating storm and tile drain systems in the physics-based, distributed-parameter, hydrologic model Gridded Surface Subsurface Hydrologic Analysis (GSSHA).

This report describes methods developed under the System Wide Water Resources Program (SWWRP). Dr. Steve Ashby, Environmental Laboratory (EL), was the SWWRP Program Manager at the time this work was conducted.

The work was performed by Dr. Charles W. Downer, Dr. Nawa Raj Pradhan, and Dr. Aaron R. Byrd of the Hydrologic Systems Branch (HF-H) of the Flood and Storm Protection Division (HF), U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). At the time of publication, Dr. Ty Wamsley was Chief, CEERD-HF. The Deputy Director of ERDC-CHL was Dr. Kevin Barry, and the Director was José E. Sánchez.

COL Jeffrey Eckstein was the Commander and Executive Director of ERDC, and Dr. Jeffery P. Holland was the Director.

This report and the software GSSHA are products of the Watershed Systems Group, Hydrologic Systems Branch, CHL, and SWWRP. For more information about GSSHA, contact Barbara Parsons, Hydrologic Systems Branch, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199. Information on GSSHA can also be found on the CHL website at http://chl.erdc.usace.army.mil/ and the GSSHA wiki at http://gsshawiki.com.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
knots	0.5144444	meters per second
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pints (U.S. liquid)	4.73176 E-04	cubic meters
quarts (U.S. liquid)	9.463529 E-04	cubic meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

1   Introduction

Background

Subsurface drainage systems are important hydrologic modifiers. A subsurface drainage system model called SUPERLINK (Ji 1998) has been added to the physics-based, distributed, hydrologic model GSSHA (Downer et. al. 2005) by Zahner (2004) as described in Ogden et al. (2011). The SUPERLINK model is capable of representing flow through a pipe network with inputs typical for an urban storm drain network or an agricultural tile drainage system.

Objective

The SUPERLINK model and its implementation in GSSHA have already been described in previously published documents (Ji 1998; Zahner 2007; Ogden et al. 2011). The purpose of this report is to describe how to use the SUPERLINK model as implemented in GSSHA to simulate storm and tile drain systems. This report describes the functioning of the SUPERLINK model as it pertains to developing inputs for the model to simulate storm and tile drain systems. Numerical considerations in the use of the model are discussed, the model inputs are described in detail, and example problems are provided with complete inputs to illustrate the points. While the Watershed Modeling System (WMS) (Nelson 2001) supports GSSHA input development and output analysis, it is important for the user to be familiar with the actual GSSHA inputs.

This document is an addendum to the GSSHA Users' Manual (Downer and Ogden 2006). Additional information on GSSHA can be found in the GSSHA's User Manual (Downer and Ogden 2006) and the GSSHA wiki: http://gsshawiki.com/gssha/Main_Page.

2   Storm Drainage Networks in GSSHA

The SUPERLINK subsurface storm sewer model (Ji 1998) was included in GSSHA by Zahner (2004) to simulate subsurface storm drainage networks and their interaction with the channel network in urbanized catchments. SUPERLINK is a general hydrodynamic model for storm sewer/channel networks (Ji 1998). It solves the full-dynamic form of the de St-Venant equations in one dimension and employs the Preissmann slot (Cunge et al. 1980) to extend the open channel flow assumptions to closed conduits flowing full and surcharged. Flow directions need not be specified a priori in the SUPERLINK scheme, and SUPERLINK can simulate reverse flow and flow in looped networks. Details of SUPERLINK and several excellent examples of the performance of the method are shown in Ji (1998).

A superlink consists of junctions which represent culverts or manholes, nodes that represent grate/curb openings in a roadway, and links that connect nodes (Figure 1). A superlink consists of one or more pipes. Each pipe has a node at each end of the pipe.

Figure 1. SUPERLINK junction, superlink, link, and node nomenclature.
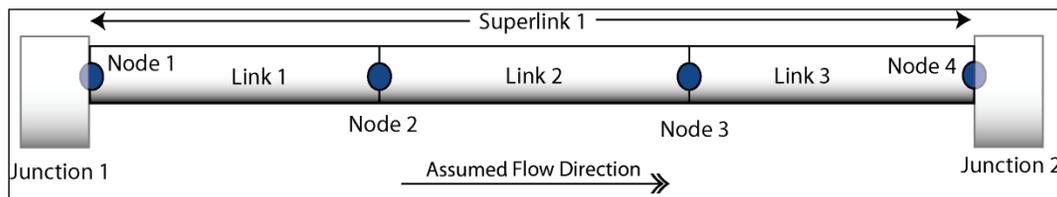
In GSSHA, the flow of surface water into junctions and nodes is calculated using the overland flow depth. Depending upon the overland flow depth, curb-side grates either behave as weir-type inlets or as orifice-type inlets (Brown et al. 2009). Flow into links from the subsurface occurs when links are defined as tile drains, and the link is below the groundwater surface. SUPERLINK can discharge onto the overland flow grid or into channels at predefined outlet junctions. Details of SUPERLINK implementation in GSSHA are provided in Ogden et al. (2012).

A SUPERLINK network consist of a series of superlinks connected at junctions. In GSSHA it is permissible to have multiple storm drainage networks in the same watershed, and the drainage systems can be looped. Figure 2 presents an example of a GSSHA model with a storm and tile drain network.

Figure 2. Example of GSSHA storm/tile drain network.
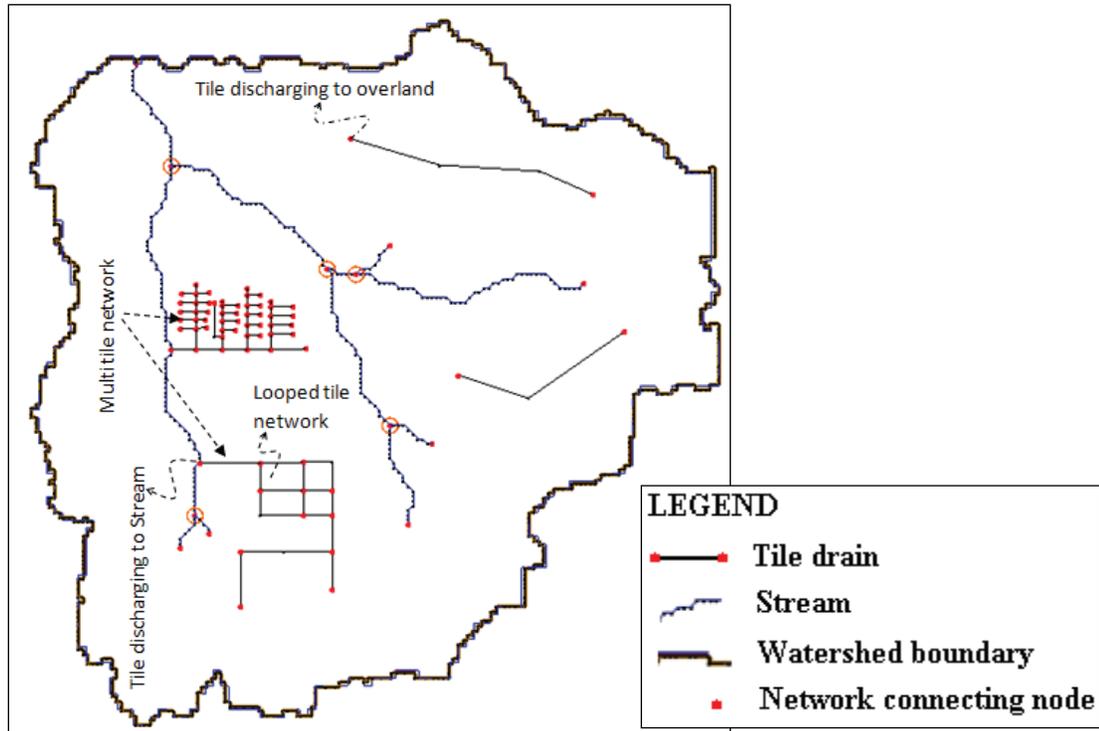
While the drainage system may connect to the stream network, the storm drain system has its own numbering system separate from the stream network. The two new GSSHA input files are the storm pipe network file (.spn) and the grid pipe file (.gpi). Both files are card-based files. The storm pipe network file describes the pipe and junction characteristics, locations, and elevations. The grid pipe file is similar to the grid stream file and is used for a similar purpose; it describes which pipes lie in which cells so that groundwater flow into tiles can be calculated. These files are specified in the project file, a card-based file that controls the GSSHA simulation. As in Downer and Ogden (2006) all control cards referenced in this document are shown in bold full caps **LIKE THIS**.

Attributes

Junctions, superlinks, and pipes all have attributes as described below.

Junction attributes

Junctions are used to define the basic SUPERLINK network. Junctions occur at the end of each superlink. Inflows and outflows can occur at the junctions. In the storm pipe network file (.spn), junctions are prescribed with the **SJUNC** card (Table 1). The card contains the following:

- junction number
- the ground surface elevation (meters (m)) at the junction (taken from the overland flow grid)
- the pipe invert elevation (m)
- manhole surface area (m²), if any
- inlet code

  - 0–9 is the number of grate inlets; 0 captures no flow
  - 10 captures all the water available in the overland grid cell that the inlet resides in
  - 888 for junctions that discharge to an overland flow cell
  - 999 for junctions that discharge into a stream node

- the location of the junction in the GSSHA grid, row and column (if the junction is connected to the stream link and node, then the stream link and node number are given instead of the cell row and column location)
- the properties of the grate or manhole.

Table 1. Format of the SJUNC card.

SJUNC	Junction #	Ground surface elevation (m)	Junction bottom elevation (m)	Manhole surface area (m2)	Inlet code	Link # / Cell row # (i)	Node # / Cell col # (j)	Weir side length (m)	Orifice diameter (m)

The inlet code defines the boundary condition at each junction. A junction can have an inlet, with the number of grates being defined from 0–10, with 10 grates resulting in all flow going into the inlet and zero resulting in no flow entering the junction.

In addition, the junction can discharge to the overland, inlet type 888, or into a channel node, type 999. If a junction discharges to the stream network, then the link and node number of the connecting stream are input instead of the cell i and j values. These boundary types specify that all the flow in the network at that junction discharges to the cell or node, regardless of the presence of inlets.

If the inlet code is defined as greater than 0 and less than 10, then these are the number of inlets for storm water from GSSHA overland flow to the superlink. Inlets of this type are gutters that function as either weirs or orifices depending on the depth of water on the overland flow relative to the size of the inlets. At lower depths, the inlets function as weirs. At

higher depths, the inlets function as orifices. Grates of larger dimension will operate as weirs to greater depths than smaller grates or grates with less opening area. The user must define the grates by specifying the weir side length and orifice diameter. The weir side length is the length of the opening. The orifice diameter is the size of the pipe that the inlet drains into. If no inlet is present at a junction, then these values should be 0.0.

Either weir flow or orifice flow equations are used to compute flow into the grate depending on the depth of overland flow (d) (m):

1. For $d \leq 0.4$ m, the weir flow equation is used.
2. For $d \geq 1.0$ m, the orifice flow equation is used.
3. For 0.4 m $< d <$ 1.0 m, the flow using the weir flow and flow equation is computed and smaller flow is used.

The flow capacity (Q) (m³ s⁻¹) of gate inlets as weirs is

$$Q = CPd^{1.5} \tag{1}$$

where:

P = perimeter of the grate (m) disregarding the side against the curb
C = discharge coefficient, 1.66.

The flow capacity of a grate inlet operating as an orifice is

$$Q = CA(2gd)^{0.5} \tag{2}$$

where:

C = orifice coefficient = 0.67
A = clear opening area of the grate (m²)
g = acceleration of gravity = 9.80 m s⁻².

Example input files for junctions are shown in Chapter 6.

Superlink attributes

Superlinks are conceptually treated as pipes that (possibly) connect a series of manholes. While flow in a superlink can be in either direction, a superlink has a nominal flow direction assigned using the numbering convention in the Watershed Modeling System (WMS*)* and GSSHA. This numbering scheme is used in GSSHA for setting up internal solution matrices, as described in Ogden et al. (2011). All superlinks should have a unique number, starting with 1 and running consecutively. Superlink numbers should increase in the downstream direction.

In the storm pipe network file (.spn), the superlinks are described by a set of cards. First is the **SLINK**, which contains the superlink number and the number of pipe cards to follow (Table 2).

Table 2. Format of the SLINK card.

SLINK	Superlink ##	# of Pipes

The **SLINK** card denotes the start of the superlink group. After the **SLINK** card is a series of node and pipe cards. There should be as many **PIPE** lines as the number of pipes specified in the **SLINK** card; there should be as many **NODE** cards as **PIPE** cards, plus one. Example input for **SLINK** cards are shown in Chapter 6.

Node attributes

Nodes in a superlink represent locations where the pipe properties, grade, or route may change, a manhole may be located, or simply a computational division point. The node spacing may vary from one superlink to the next, and pipe lengths can vary within a superlink. Nodes are similar to junctions and require essentially the same input (Table 3).

Table 3. Format of the NODE card.

NODE	Node ##	Ground surface elevation (m)	Invert elevation (m)	Manhole surface area (m2)	Inlet code	Cell row # (i)	Cell col # (j)	Weir side length (m)	Orifice diameter (m)

The subsurface drainage system interacts with the surface water system at nodes (and junctions) through manholes and inlet grates, the same as at junctions. The number of grates determines how much of the overland flow is captured with 10 being 100% of the water in the cell. Water can

flow into the node through the inlets and can flow out of the node through the manholes. Water is also stored in the manholes. If a node connects to a junction, its inlet code is 777; otherwise, it is 0–10, describing the number of manholes as defined for junctions, 0 for no flow and 10 for all of the water in the grid cell. If no manhole is present at a node, then the manhole cross-section should be 0.0. There is no discharge to a grid cell or stream node from a node (Figure 3).

Figure 3. Inlet type description.

Inlet Type	
0-10	## of grate inlets in the roadway; 10 = capture all flow in cell, 0 = capture no flow
777	node connecting to a junction

While there are no requirements for the spacing of the nodes, the superlink solution requires that the node spacing near the junctions be small, on the order of 10 m or 25% or less than the total superlink length. This is due to the assumption that the head at the first node from the end of the junction is the same as the head at the junction. For numerical stability, the node spacing should increase incrementally up to the maximum node spacing. The user can either enter the nodes required for computational purposes directly or just define the physical network with the minimum numbers of links and nodes, put the **SUPERLINK_C_OPT** card in the project file, and GSSHA will supply the required computational nodes to the physical network. For more information, see the examples at the end of this report.

Pipe attributes

The **PIPE** card represents a pipe segment in a superlink. Pipe attributes are assigned for each pipe with the **PIPE** card. The **PIPE** card is used to define the pipe number, cross-section type and properties, slope, roughness, and additional information to specify whether or not the pipe is a tile drain (Table 4).

Table 4. Format of the PIPE card.

PIPE	Pipe ##	X-Section Type	Diameter or Height (m)	Width (m)	Slope	Roughness	Length (m)	Conductance (cm hr-1)	Drain spacing (m)

There are currently two supported formats for pipe cross sections: circular type 1 and rectangular type 2 (Figure 4).

Figure 4. Cross-section types.

Cross-section Type	
1	Circular (set width = diameter or 0.0)
3	Rectangular

If a circular pipe is specified, the width value in the table is ignored, but a value must still be entered. If a rectangular cross section is selected, then both the height and width are used in the calculations.

Pipes in a superlink represent both storm drain and tile drain pipes. Tile drains are defined by the hydraulic conductivity of the material surrounding the pipe. If the hydraulic conductivity of the pipe is anything other than zero, the pipe becomes a tile drain. A storm drain that is not *leaky* has a conductance of 0.0. The value of hydraulic conductivity should be 0.0 or greater. Negative values have no physical meaning and may cause inaccurate, unstable, or physically meaningless results. For tile drains, the flow into the pipe is calculated along the length of the pipe and added to the downstream junction.

The hydraulic conductivity of a tile drain is specified in centimeters per hour (cm hr^{-1}). The conductance term includes the lateral soil hydraulic conductivity multiplied by a factor indicating what portion of the pipe is perforated (e.g., a pipe with perforations around half the pipe would have a factor of 0.5; this pipe in a silty soil with horizontal conductivity of 10 cm hr^{-1} would have a conductance of 5 cm hr^{-1}).

The distribution of tile drains influences the flow of groundwater into the individual tiles and must be accounted for in the calculation of tile drain flow. The drain spacing (*L*) (m) is the distance between tile drain pipes in the network. As discussed in Chapter 3, this distance is used to determine the shape of the groundwater surface in the vicinity of the tile drains. If the hydraulic conductivity of the pipe is greater than zero, then this value must also be greater than zero. If a hydraulic conductivity greater than zero is input for the materials surrounding any pipe in the network, then tile drainage will be computed, and the **GRID_PIPE** file must be included in the inputs. Example input sets for the **PIPE** card are shown in Chapter 6.

Topology

The SUPERLINK network may be looped or not. It may be one or many superlinks. It may connect at a junction to a grid cell or at a stream node. The connections between superlinks and junctions are defined through a set of **CONNECT** cards at the beginning of the storm pipe network file (.spn), specified with the **STORM_SEWER** project card. There is one connect card for each superlink. In the **CONNECT** cards, the upstream and downstream junctions are assigned (Table 5).

Table 5. Format of the CONNECT cards.

CONNECT	Superlink #	Upstream Junction #	Downstream Junction #

Whenever tile drains are included in the network, the other file that must be included is the grid pipe file (.gpi), which specifies what segment of each pipe lies in which grid cells. The grid pipe file is specified with the **GRID_PIPE** card in the project file. For every cell that contains at least some fragment of a pipe, a **CELLIJ** card is included in the **GRID_PIPE** file. The **CELLIJ** card contains the cell row and column number. The number of pipe fragments in each cell is specified with the **NUMPIPES** card. For each pipe fragment in the **CELLIJ,** a **SPIPE** card is included. The **SPIPE** card lists the superlink number, the pipe number, and the fraction of the pipe in the cell. Because the pipe network can be assigned without regard to the grid size, a grid cell can contain fractions of a pipe or pipes and/or multiple pipes.

It is important that the pipe number, not the node number, is included in the **SPIPE** card. In a superlink, pipe 1 lies between nodes 1 and 2. For example, putting a 2 in the third column of the **SPIPE** card indicates *pipe* 2, not *node* 2, lies in the pipe cell. If the superlink has only one pipe, placing a 2 in this location will lead to an error because there is no pipe 2 in the superlink. Even though the second node may indeed lie in the cell, that information is not relevant in the grid pipe file. The format of the grid pipe cell is shown in Table 6.

Table 6. Grid pipe file format.

GRIDPIPEFILE			
PIPECELLS	# of cells that have a pipe in them		
CELLIJ	Cell Row	Cell Col	
NUMPIPES	# of pipe segments		
SPIPE	superlink #	PIPE #	Fraction of pipe length
SPIPE	superlink #	PIPE #	Fraction of pipe length
SPIPE	superlink #	PIPE #	Fraction of pipe length
...			
CELLIJ	Cell Row	Cell Col	
NUMPIPES	# of pipe segments		
SPIPE	superlink #	PIPE #	Fraction of pipe length
SPIPE	superlink #	PIPE #	Fraction of pipe length
SPIPE	superlink #	PIPE #	Fraction of pipe length
...			
CELLIJ	Cell Row	Cell Col	
NUMPIPES	# of pipe segments		
SPIPE	superlink #	PIPE #	Fraction of pipe length
SPIPE	superlink #	PIPE #	Fraction of pipe length
SPIPE	superlink #	PIPE #	Fraction of pipe length
...			

Computation considerations in the network layout

The assumption in the SUPERLINK method that the head at the first computational node in a superlink is the same as the head at the junction makes the spacing of nodes in the superlink very important. Because of this assumption, the length of the first pipe in each superlink must be very short, on the order of 10 m and less than 25% of the total superlink length. Subsequent pipes should be increased incrementally in length, up to the maximum node length. This can be done by the user, or the user can input a network with only junctions and superlinks, no internal nodes, and include the **SUPERLINK_C_OPT** card in the project file. When this card is included in the project file, GSSHA will analyze the SUPERLINK network and add computational nodes between the existing nodes, if needed, while preserving the original SUPERLINK network of pipes and nodes. If the **SUPERLINK_C_OPT** card is specified and the network contains superlinks with more than one pipe, GSSHA will add nodes near the superlink junctions as required to satisfy the criteria above. GSSHA will still add nodes to superlinks with no internal nodes, only junctions, to

meet the required node spacing. Examples of both approaches are shown in Chapter 6.

High-head release option

In a standard application, inlets allow flow into SUPERLINK only. The optional project card, **HIGH_HEAD_RELEASE,** allows SUPERLINK nodes or junctions to discharge back to the overland if the head in the respective junction or node exceeds the topographic ground surface elevation. At those high-pressure locations, junction inlets and node inlets, type 0–9, cease to accept the overland discharge and instead act as outlet points by releasing discharge to overland flow.

3 Tile Drains

As described in Chapter 2, pipes in SUPERLINK represent both storm drains and tile drains depending on the value of hydraulic conductivity specified for the pipe. A storm drain has a conductance of 0.0; for any other value of conductance, the pipe is a tile drain. Tiles drain the saturated groundwater media. For tile drains to have any effect on the simulation, the water table must be specified with the **WATER_TABLE** card in the project file, which is used to provide the groundwater elevations in the model domain. Tile drains are typically used in simulations with calculated, time-varying groundwater elevations. Tile drains used with a static **WATER_TABLE** and without actual groundwater simulations will give the effects of the water table on tile flow but without the tile drains affecting the water table. Groundwater simulations in GSSHA are specified by including the **GW_SIMULATION** card and other required cards in the project file. Refer to the GSSHA User's Manual (Downer and Ogden 2006) for additional information on the **WATER_TABLE**, **GW_SIMULATION** and additional required project cards required for simulating a static or moving groundwater free water surface in GSSHA. For the tile drains to have an effect on the simulation, one or more tile drains must be below the groundwater surface for at least part of the simulation.

Tile drains are typically placed parallel within agricultural fields at some specified spacing (*L*) (m), the drain spacing specified in the **PIPE** card. The tile drains result in a drawdown of the local water table around the tile drain pipes, as shown in Figure 5. The drainage to tile from ground water under this common condition can be calculated with one of two optional methods, the U.S. Department of Agriculture (USDA) DRAINMOD method (Skaggs 1980) or Cooke et al. (2001) method. Both methods are considered accurate, and user preference would dictate the selection of methods.

Figure 5. Schematic of water table drawdown from parallel drain tubes.
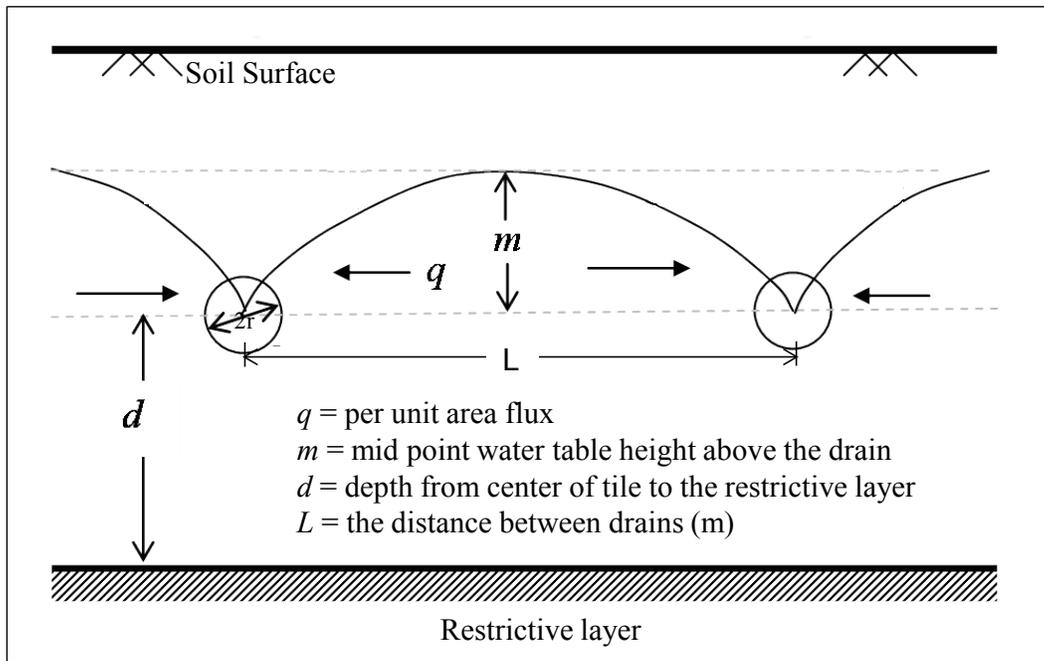
DRAINMOD

The flux resulting from a midpoint water table elevation of m may be approximated as equal to the steady rainfall rate that would cause the same equilibrium m value. The equation for drainage flux may be written as

$$ j = \frac{8K\,d_e m + 4Km^2}{CL^2} \tag{3} $$

where:

$\quad\quad j$ = per unit area flux (cm hr^{-1})
$\quad\ d_e$ = equivalent depth (m)
$\quad m$ = midpoint water table height above the drain (m)
$\quad\ L$ = the distance between drains (m)
$\quad\ K$ = effective lateral hydraulic conductivity (cm hr^{-1})
$\quad\ C$ = 1 in the present version.

Hooghoudt (van Schilfgaarde 1974) characterized flow to cylindrical drains by considering radial flow in the region near the drains and applying the Dupuit-Forchheimer (D-F) assumptions (Dupuit 1863; Forchheimer 1930) to the region away from the drains. The Hooghoudt analysis has been widely used to determine an equivalent depth (d_e), which will tend to

correct drainage fluxes predicted by Equation 3 for convergence near the drain. Moody (1967) examined Hooghoudt's solutions and presented the following equations from which d_e can be obtained.

For $0 < d/L < 0.3$

$$d_e = \frac{d}{1 + \dfrac{d}{L}\left\{\dfrac{8}{\pi}\ln\left(\dfrac{d}{r}\right) - \alpha\right\}} \qquad (4)$$

where:

$\quad d$ = depth of the aquifer below the tile drain (m) as shown in Figure 5
$\quad r$ = radius of the drainage pipe (m)

$$\alpha = 3.55 - \frac{1.6d}{L} + 2\left(\frac{2}{L}\right)^2 \qquad (5)$$

For $d/L > 0.3$

$$d_e = \frac{L\pi}{8\left\{\ln\left(\dfrac{L}{r}\right) - 1.15\right\}} \qquad (6)$$

The total flow Q(m³ hr⁻¹)into the pipe is $0.02\pi rqX$, where X is the length of the pipe (m).

Cooke at al.

In Cooke et al. (2001), the flow rate at the tile drain (m² hr⁻¹) from each side is computed as

$$q = \frac{0.01K}{L}(2d_e m + m^2) \qquad (7)$$

d_e is defined as (van der Molen and Wesseling (1991))

$$d_e = \frac{L\pi}{8\left\{\ln\left(\dfrac{L}{\pi r}\right) + F(x)\right\}}$$ (8)

where:

   x = 2πd/L,

and function *F(x)* is defined as

$$F(x) = \sum_{n=1}^{\infty} \frac{4\exp(-2nx)}{n(1 - \exp(-2nx))}$$ (9)

with

   n = 1, 3, 5

The total flow *Q* to the tile drain is 2*qX*.

The Cooke method is the default in GSSHA. To use the DRAINMOD method to compute groundwater flow into the tile drains, include the card **SUPERLINK_DRAINMOD** in the GSSHA project file.

Additional considerations

When using tile drains in a storm drain network, it is important to properly assign the elevations of the nodes with respect to the ground surface and the bedrock surface. Nodes at the ends of pipes that are tile drains must be at elevations greater than the bedrock and lower than the ground surface elevation. Also, if the subsurface drain is above the water table, no water will be drained. Users should be aware that land, water table, and bedrock surfaces developed by interpolation from point data or other means and then composited to a grid may contain significant local errors. The user should always check that the elevation of nodes, land surface, water table, and bedrock are accurate and that the proper relationships exist among them. The WMS can be used to help determine these relations and correct any problems with the inputs.

4 Project File

In GSSHA, the model simulation is controlled by a card-based file called the project file, which WMS gives the extension .prj. The following card is required in the project file for any SUPERLINK simulation (Table 7).

Table 7. Card required in SUPERLINK simulation.

Card	Input	Description
STORM_SEWER	Filename - *.spn	File containing link/node/pipe information

If the pipe hydraulic conductivity of any pipe in the **STORM_SEWER** file is greater than zero, the **GRID_PIPE** card, which contains information about the location of pipe in the computational grid, must be included (Table 8).

Table 8. GRID_PIPE card.

Card	Input	Description
GRID_PIPE	Filename - *.gpi	File containing pipe topological information

Three optional cards can be used (Table 9).

Table 9. Optional cards.

Card	Input	Description
SUPERLINK_C_OPT	none	Redistributes nodes for computations
SUPERLINK_DRAINMOD	none	Use DRAINMOD method for tile drains
HIGH_HEAD_RELEASE	none	Allows flow back to overland due to high-head build up in SUPERLINK.

5   Output

When using the SUPERLINK model, GSSHA automatically writes a file
named superlink_flows.out to the directory where the project file is
located. The superlink_flows.out file contains the total volumes (m^3) and
flows (m^3 s^{-1}) into and out of the SUPERLINK network for every call (each
time-step) to the SUPERLINK model. There are five columns in this
output file with the following information:

- Call #
- Volume from GSSHA to SUPERLINK
- Volume from SUPERLINK to GSSHA
- Discharge from GSSHA to SUPERLINK
- Discharge from SUPERLINK to GSSHA.

These volumes and discharges include all flows into the SUPERLINK
model and all flows out of the SUPERLINK model. All volumes and flows
are for an individual time-step. This file can be used to produce plots of
total flow into and out of the SUPERLINK network, as shown in the
examples in Chapter 6. This file can become quite large for long simulation
periods and may need to be removed after the simulation is complete.
Information from individual junctions and nodes can be output in point
time-series.

Point time-series of inflows and outflows from any junction or node can be
output at the **MAP_FREQ** time-step by including cards in the project file
that specify input and output cards as shown below in Table 10.

Table 10. Superlink output cards.

Project Card	Input	Description
SUPERLINK_JUNC_LOCATION	filename	Junction output locations
SUPERLINK_NODE_LOCATION	filename	Node output locations
SUPERLINK_JUNC_FLOW	filename	Time series data for flows into/out of junctions
SUPERLINK_NODE_FLOW	filename	Time series data for flows into/out of nodes

Inputs are similar to those in the **IN_HYD_LOCATION** file in that the input files contain the number of junctions or nodes followed by the junction or node locations. The **SUPERLINK_JUNC_LOCATION** file contains the number of junctions followed by the junction numbers:

```
# Junctions
Junction # 1
Junction # 2
...
Junction N-1
Junction N
```

For example, if the user wanted flow output from junctions 2 and 4, the input would be

```
2
2
4
```

For **SUPERLINK_NODE_LOCATION,** the file is the same except it contains the link and the node number:

```
#Nodes
Link # 1 Node # 1
Link # 1 Node # 1
...
Link # N-1 Node # N-1
Link # N Node # N
```

For example, if the user wanted output from superlink 1, node 3, and superlink 5, node 4, the input would be

```
2
1 3
5 4
```

The output in both files is flow into or out of the junction or node in $m^3 s^{-1}$, or $ft^3 s^{-1}$ if the **CFS_OUT** card is included in the project file, from each of the junctions/nodes. Format of the file is *time* in the first column and *flow* for each of the junctions/nodes in sequential columns as listed in the input files. For an event, the output might look like the following:

```
0.0 0.0 0.0
15.0 0.1 0.2
30.0 0.2 0.3
45.0 0.5 0.5
...
```

Flows into junctions or nodes are positive. Flows from the junction or node back to the overland or channel are negative.

6 Examples

These two examples illustrate the types of problems that can be solved with the SUPERLINK model, the input files required, and SUPERLINK output. These examples are highly conceptual and simplified and do not represent actual projects.

Example 1–Ji (1998) SUPERLINK example coupled with GSSHA overland runoff

The first example is the network found in the original Ji (1998) paper. In this example, a network of five superlinks is defined with six junctions (Figure 6). The Ji network is included in a 20 × 20 GSSHA grid with a stream network (Figure 7). Elevations of the grid cells are shown in Figure 8. Within each superlink, there are computational nodes added in

Figure 6. Ji (1998) SUPERLINK network coupling with GSSHA overland flow. This network is defined in the data file super.spn.

Figure 7. Including Ji (1998) SUPERLINK network (red) in a GSSHA 20 × 20 cell grid example, which includes a stream network (blue).

Figure 8. Elevation data in rows and columns of the 20 × 20 grids example and the SUPERLINK network location.

Columns ------>

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	143.145	140.871	138.471	136.071	133.672	131.272	128.872	126.472	124.072	121.673	119.273	116.873	114.473	112.073	109.674	107.274	104.874	102.474	100.074	97.675
2	137.077	134.808	132.556	130.304	127.943	125.543	123.144	120.744	118.344	115.944	113.544	111.145	108.745	106.345	103.945	101.545	99.146	96.746	94.346	96.630
3	131.147	128.723	126.471	124.218	121.966	119.714	117.415	115.015	112.616	110.216	107.816	105.416	103.016	100.617	98.217	95.817	93.417	91.018	93.570	101.021
4	125.217	122.706	120.385	118.133	115.881	113.629	111.376	109.124	106.872	104.488	102.088	99.688	97.288	94.888	92.489	90.089	87.689	89.510	97.959	103.403
5	119.287	116.776	114.300	112.048	109.796	107.543	105.291	103.039	100.787	98.535	96.282	93.960	91.560	89.160	86.760	84.360	86.450	94.898	100.342	105.786
6	113.358	110.846	108.334	105.962	103.710	101.458	99.206	96.954	94.701	92.449	90.197	87.945	85.693	83.432	81.032	82.390	91.837	97.281	102.725	108.169
7	107.428	104.916	102.405	99.893	97.625	95.373	93.121	90.868	88.616	86.364	84.112	81.860	79.607	77.355	83.332	88.776	94.220	99.664	105.108	110.552
8	101.498	98.986	96.475	93.963	91.540	89.287	87.035	84.783	82.531	80.279	78.026	75.774	73.522	78.593	85.206	91.159	96.603	102.047	107.491	112.935
9	95.568	93.057	90.545	88.033	85.522	83.202	80.950	78.698	76.446	74.193	71.941	69.689	73.847	80.460	87.074	93.542	98.986	104.430	109.874	115.318
10	89.638	87.127	84.615	82.103	79.592	77.117	74.865	72.612	70.360	68.108	65.856	69.101	75.714	82.328	88.942	95.555	101.369	106.813	112.257	117.701
11	83.708	81.197	78.685	76.174	73.662	71.150	68.779	66.527	64.275	62.023	64.354	70.968	77.582	84.196	90.809	97.423	103.752	109.196	114.640	120.084
12	77.779	75.267	72.755	70.244	67.732	65.220	62.709	60.442	58.190	59.608	66.222	72.836	79.449	86.063	92.677	99.291	105.904	111.579	117.023	122.467
13	71.849	69.337	66.826	64.314	61.802	59.291	56.779	54.357	54.862	61.476	68.090	74.703	81.317	87.931	94.544	101.158	107.772	113.962	119.406	124.850
14	65.919	63.407	60.896	58.384	55.872	53.361	50.849	50.692	56.730	63.343	69.957	76.571	83.185	89.798	96.412	103.026	109.639	116.253	121.788	127.233
15	59.989	57.478	54.966	52.454	49.907	45.832	47.930	54.212	59.908	65.604	71.825	78.438	85.052	91.666	98.280	104.893	111.507	118.121	124.171	129.615
16	54.059	51.548	48.436	44.361	40.285	44.695	52.035	57.731	63.427	69.123	74.820	80.516	86.920	93.533	100.147	106.761	113.375	119.988	126.554	131.998
17	46.965	42.890	38.814	34.739	41.859	49.802	55.554	61.250	66.947	72.643	78.339	84.035	89.731	95.428	102.015	108.629	115.242	121.856	128.470	134.381
18	34.663	31.876	30.881	38.824	46.767	53.378	59.074	64.770	70.466	76.162	81.858	87.555	93.251	98.947	104.643	110.496	117.110	123.724	130.337	136.764
19	20.899	19.525	34.520	43.731	51.201	56.897	62.593	68.289	73.985	79.682	85.378	91.074	96.770	102.466	108.163	113.859	119.555	125.591	132.205	138.819
20	7.692	22.687	37.683	48.639	54.720	60.416	66.113	71.809	77.505	83.201	88.897	94.593	100.290	105.986	111.682	117.378	123.074	128.771	134.467	140.686

Rows ----->

the input file for computational purposes (Table 11). Since the Ji example does not include any tile drains (the hydraulic conductivity is zero in each **SPIPE** card), there is no need to include the **GRID_PIPE** file. In this example, water enters the junctions through grates and flows back onto the overland at junctions 4 and 6. The flows into SUPERLINK and back out onto the overland flow plane are shown in Figure 9. Flows into and out of each junction are shown in Figure 10.

Table 11. Storm pipe network file for Example 1.

```
CONNECT 1 1 2
CONNECT 2 2 3
CONNECT 3 3 4
CONNECT 4 2 5
CONNECT 5 5 6
CONNECT 6 5 3
SJUNC 1 103.71000 98.71000 1.000000 9 6 5 0.2 0.2
SJUNC 2 85.522000 80.522000 1.000000 0 9 5 0.2 0.2
SJUNC 3 71.150000 66.150000 1.000000 9 11 6 0.2 0.2
SJUNC 4 59.291000 54.291000 1.000000 888 13 6 0.2 0.2
SJUNC 5 76.174000 71.174000 1.000000 0 11 4 0.2 0.2
SJUNC 6 64.314000 59.314000 1.000000 888 13 4 0.2 0.2
SLINK 1 8
NODE 1 103.71000 98.71000 0.000000 777 6 5 0.5 0.5
NODE 2 101.43750 96.43750 1.000000 0 6 5 0.5 0.5
NODE 3 99.165000 94.16500 0.000000 0 7 5 0.5 0.5
NODE 4 96.892500 91.89250 1.000000 0 7 5 0.5 0.5
NODE 5 94.620000 89.62000 0.000000 0 7 5 0.5 0.5
NODE 6 92.347500 87.34750 1.000000 0 8 5 0.5 0.5
NODE 7 90.075000 85.07500 0.000000 0 8 5 0.5 0.5
NODE 8 87.802500 82.80250 0.000000 0 8 5 0.5 0.5
NODE 9 85.522000 80.53000 1.000000 777 9 5 0.5 0.5
PIPE 1 1 0.6000000 0.600000 0.060627 0.01000 10.000000 0.000 0.0
PIPE 2 1 0.6000000 0.600000 0.060627 0.01000 20.000000 0.000 0.0
PIPE 3 1 0.6000000 0.600000 0.060627 0.01000 40.000000 0.000 0.0
PIPE 4 1 0.6000000 0.600000 0.060627 0.01000 50.000000 0.000 0.0
PIPE 5 1 0.6000000 0.600000 0.060627 0.01000 50.000000 0.000 0.0
PIPE 6 1 0.6000000 0.600000 0.060627 0.01000 30.000000 0.000 0.0
PIPE 7 1 0.6000000 0.600000 0.060627 0.01000 20.000000 0.000 0.0
PIPE 8 1 0.6000000 0.600000 0.060627 0.01000 10.000000 0.000 0.0
SLINK 2 6
NODE 1 85.522000 80.522000 1.000000 777 9 5 0.5 0.5
NODE 2 83.126670 78.126670 1.000000 0 9 5 0.5 0.5
NODE 3 80.731330 75.731330 1.000000 0 10 5 0.5 0.5
NODE 4 78.336000 73.336000 1.000000 0 10 5 0.5 0.5
NODE 5 75.940670 70.940670 1.000000 0 11 6 0.5 0.5
NODE 6 73.545330 68.545330 1.000000 0 11 6 0.5 0.5
NODE 7 71.150000 66.150000 1.000000 777 11 6 0.5 0.5
PIPE 1 1 0.50000 0.50000 0.07186 0.02000 10.000000 0.00 0.0
PIPE 2 1 0.50000 0.50000 0.07186 0.02000 20.000000 0.00 0.0
PIPE 3 1 0.50000 0.50000 0.07186 0.02000 50.000000 0.00 0.0
PIPE 4 1 0.50000 0.50000 0.07186 0.02000 50.000000 0.00 0.0
PIPE 5 1 0.50000 0.50000 0.07186 0.02000 20.000000 0.00 0.0
PIPE 6 1 0.50000 0.50000 0.07186 0.02000 10.000000 0.00 0.0
```

```
SLINK 3 6
NODE 1 71.150000 66.150000 1.000000 777 11 6 0.5 0.5
NODE 2 69.173820 64.173820 1.000009 0 11 6 0.5 0.5
NODE 3 67.197640 62.197640 1.000000 0 12 6 0.5 0.5
NODE 4 65.221460 60.221460 1.000009 0 12 6 0.5 0.5
NODE 5 63.245270 58.245270 1.000000 0 13 6 0.5 0.5
NODE 6 61.269090 56.269090 1.000000 0 13 6 0.5 0.5
NODE 7 59.291000 54.291000 1.000009 777 13 6 0.5 0.5
PIPE 1 1 0.500000 0.500000 0.0593 0.02000 10.000000 0.00 0.0
PIPE 2 1 0.500000 0.500000 0.0593 0.02000 20.000000 0.00 0.0
PIPE 3 1 0.500000 0.500000 0.0593 0.02000 50.000000 0.00 0.0
PIPE 4 1 0.500000 0.500000 0.0593 0.02000 50.000000 0.00 0.0
PIPE 5 1 0.500000 0.500000 0.0593 0.02000 20.000000 0.00 0.0
PIPE 6 1 0.500000 0.500000 0.0593 0.02000 10.000000 0.00 0.0
SLINK 4 6
NODE 1 85.52200 80.522000 1.000000 777 9 5 0.5 0.5
NODE 2 83.96400 78.964000 1.000000 0 9 5 0.5 0.5
NODE 3 82.40600 77.406000 1.000000 0 10 4 0.5 0.5
NODE 4 80.84800 75.848000 1.000000 0 10 4 0.5 0.5
NODE 5 79.29000 74.290000 1.000000 0 10 4 0.5 0.5
NODE 6 77.73200 72.732000 1.000000 0 11 4 0.5 0.5
NODE 7 76.17400 71.174000 1.000000 777 11 4 0.5 0.5
PIPE 1 1 0.500000 0.500000 0.04674 0.01000 10.000000 0.00 0.0
PIPE 2 1 0.500000 0.500000 0.04674 0.01000 20.000000 0.00 0.0
PIPE 3 1 0.500000 0.500000 0.04674 0.01000 50.000000 0.00 0.0
PIPE 4 1 0.500000 0.500000 0.04674 0.01000 50.000000 0.00 0.0
PIPE 5 1 0.500000 0.500000 0.04674 0.01000 20.000000 0.00 0.0
PIPE 6 1 0.500000 0.500000 0.04674 0.01000 10.000000 0.00 0.0
SLINK 5 6
NODE 1 76.17400 71.174000 1.000000 777 11 4 0.5 0.5
NODE 2 74.19730 69.197330 1.000000 0 11 4 0.5 0.5
NODE 3 72.22060 67.220670 1.000000 0 12 4 0.5 0.5
NODE 4 70.24400 65.244000 1.000000 0 12 4 0.5 0.5
NODE 5 68.26730 63.267330 1.000000 0 12 4 0.5 0.5
NODE 6 66.29067 61.290670 1.000000 0 13 4 0.5 0.5
NODE 7 64.31400 59.314000 1.000000 777 13 4 0.5 0.5
PIPE 1 1 0.500000 0.500000 0.0593 0.02000 10.000000 0.00 0.0
PIPE 2 1 0.500000 0.500000 0.0593 0.02000 20.000000 0.00 0.0
PIPE 3 1 0.500000 0.500000 0.0593 0.02000 50.000000 0.00 0.0
PIPE 4 1 0.500000 0.500000 0.0593 0.02000 50.000000 0.00 0.0
PIPE 5 1 0.500000 0.500000 0.0593 0.02000 20.000000 0.00 0.0
PIPE 6 1 0.500000 0.500000 0.0593 0.02000 10.000000 0.00 0.0
SLINK 6 6
NODE 1 76.174000 71.174000 1.000000 777 11 4 0.5 0.5
NODE 2 75.336600 70.336670 1.000000 0 11 4 0.5 0.5
NODE 3 74.499300 69.499330 1.000000 0 11 5 0.5 0.5
NODE 4 73.662000 68.662000 1.000000 0 11 5 0.5 0.5
NODE 5 72.824670 67.824670 1.000000 0 11 5 0.5 0.5
NODE 6 71.987330 66.987330 1.000000 0 11 6 0.5 0.5
NODE 7 71.150000 66.150000 1.000000 777 11 6 0.5 0.5
PIPE 1 1 0.500000 0.500000 0.02512 0.01000 10.000000 0.00 0.0
PIPE 2 1 0.500000 0.500000 0.02512 0.01000 20.000000 0.00 0.0
PIPE 3 1 0.500000 0.500000 0.02512 0.01000 50.000000 0.00 0.0
PIPE 4 1 0.500000 0.500000 0.02512 0.01000 50.000000 0.00 0.0
PIPE 5 1 0.500000 0.500000 0.02512 0.01000 20.000000 0.00 0.0
PIPE 6 1 0.500000 0.500000 0.02512 0.01000 10.000000 0.00 0.0
```

Figure 9. Total flow to and from SUPERLINK network shown in Figure 6.
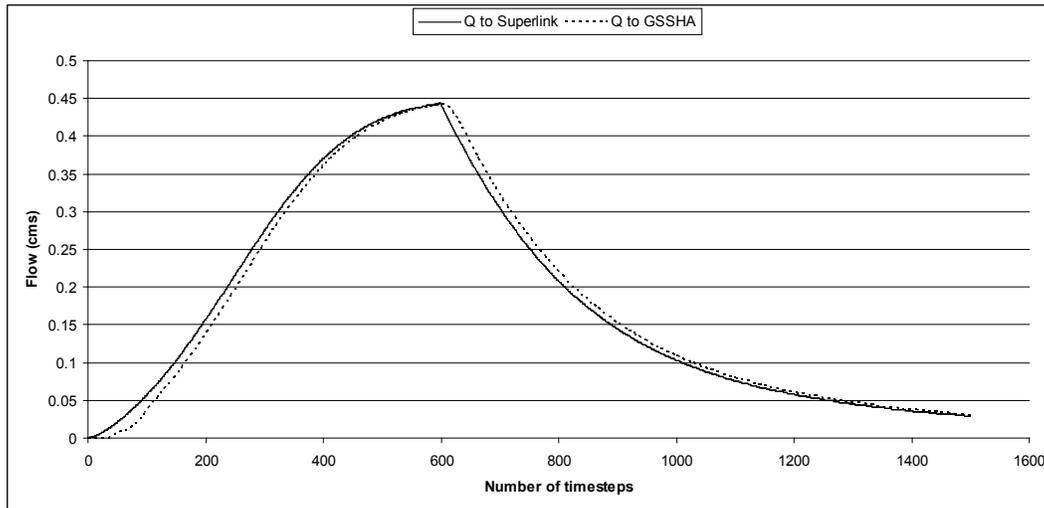

Figure 10. Flow at each junction in Figure 6. Negative flows are flows out of junction.
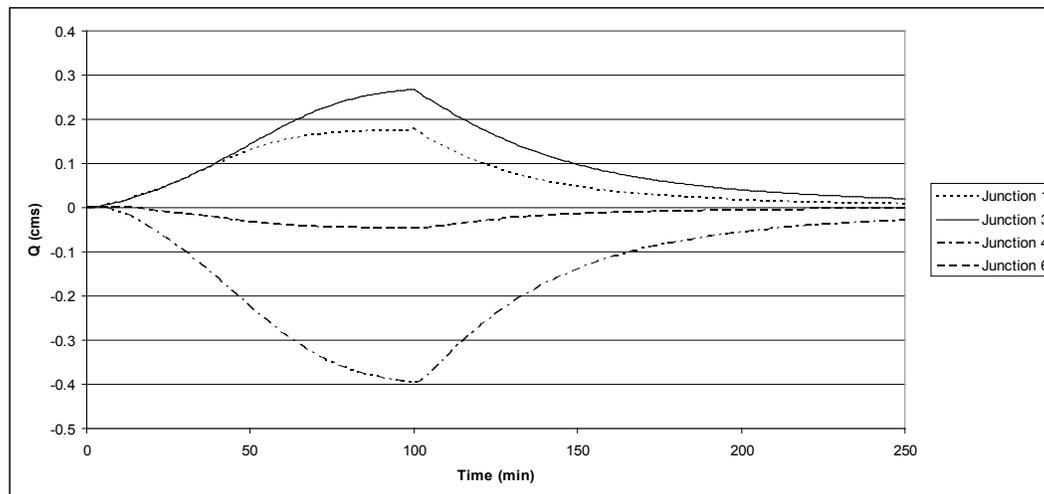
Example 2–Tile drain project

In this example, a very simple SUPERLINK network is located in an 11 × 10 GSSHA grid. The network contains five junctions and four superlinks (Figure 11). In this case, the superlink pipes are tile drains because the hydraulic conductivity of the media surrounding the pipe is greater than zero (Table 12). For that reason, the **GRID_PIPE** file, Table 13, must be included in the inputs. The tile drains receive groundwater while water from the overland enters through grates at the junctions. Flow from the SUPERLINK network enters the channel at link 4, node 3, from Junction 5. Ground surface, water table, and bedrock elevations are shown in Figure 12. Flow into and out of the SUPERLINK network is shown in Figure 13. The shape of the hydrograph is related to the rainfall pattern.

In this example, there are no nodes in addition to the nodes at the junctions. For this network to work in GSSHA, the **SUPERLINK_C_OPT** card must be included in the project file; including this card results in multiple interior nodes being generated in each superlink.

Figure 11. Tile network coupled with GSSHA overland flow.
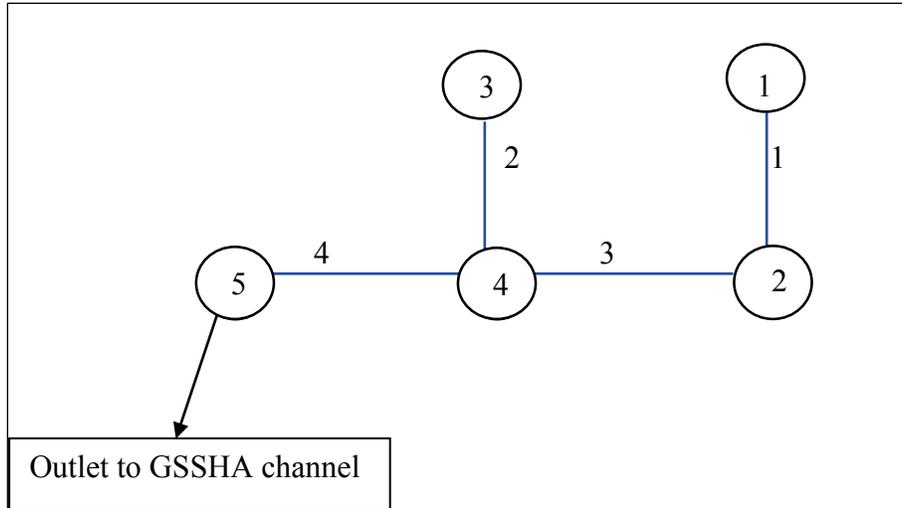
Table 12. Storm pipe network file for Example 2.

```
CONNECT 1 1 2
CONNECT 2 3 4
CONNECT 3 2 4
CONNECT 4 4 5
SJUNC 1 75.157 73.157 1.000000 4 1500.0 500.0 5 4 0.1
0.1
SJUNC 2 66.670 64.670 1.000000 1 1200.0 500.0 5 5 0.1 0.1
SJUNC 3 73.980 71.980 1.000000 4 1000.0 600.0 4 4 0.1 0.1
SJUNC 4 65.329 63.329 1.000000 1 800.0 600.0 4 5 0.1 0.1
SJUNC 5 64.776 62.776 1.000000 999 1000.0 400.0 4 3
SLINK 1 1
NODE 1 75.157 73.157 0.000000 777 1500.0 500.0 5 4 0.1 0.1
NODE 2 66.670 64.670 1.000000 777 1400.0 500.0 5 5 0.1 0.1
PIPE 1 1 0.500000 0.50000 0.042425 0.0002000 200.000000 0.000 0.0
SLINK 2 1
NODE 1 73.980 71.980 1.000000 777 1200.0 500.0 4 4 0.1 0.1
NODE 2 65.329 63.329 1.000000 777 1100.0 500.0 4 5 0.1 0.1
PIPE 1 1 0.500000 0.50000 0.043255 0.0002000 200.000000 0.000 0.0
SLINK 3 1
NODE 1 66.670 64.670 1.000000 777 1000.0 600.0 5 5 0.1 0.1
NODE 2 65.329 63.329 1.000000 777 900.0 600.0 4 5 0.1 0.1
PIPE 1 1 0.500000 0.50000 0.006705 0.0002000 200.000000 0.000 0.0
SLINK 4 1
NODE 1 65.329 63.329 1.000000 777 1200.0 500.0 4 5 0.1 0.1
NODE 2 64.776 62.776 1.000000 777 1100.0 500.0 3 5 0.1 0.1
PIPE 1 1 0.500000 0.50000 0.002765 0.0002000 200.000000 0.00 0.0
```

Figure 2. GSSHA input maps for tile drain project, Example 2: (a) Surface ELEVATION map with tiles (red) and streams (blue) superimposed; (b) Water table map; (c) Bedrock elevation map. Note: First row of cells with zeroes falls outside the active model boundary.

Surface ELEVATION map
```
north: 1100.300000
south: 0.300000
east: 1000.000000
west: 0.000000
rows: 11
cols: 10
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
92.887285 92.082626 93.327480 93.185700 93.043926 92.902151 92.760379 92.618602 92.476825 94.941225
86.237121 81.714006 78.147867 79.609053 81.070241 82.531427 83.327643 83.185866 86.792138 91.756893
79.158978 76.003267 72.188339 73.931793 75.156766 75.034210 74.896690 78.643053 83.607807 90.871730
72.080836 68.925122 64.776889 65.329492 66.671088 66.917757 73.675424 76.396022 80.423475 90.827578
65.002692 61.157752 54.988974 56.400519 57.812062 61.922098 68.546359 74.185046 77.239144 90.783429
57.924550 51.487541 46.057112 47.650549 48.547990 53.549681 60.542717 69.648478 74.054813 90.739275
49.550605 44.120177 38.689748 36.759317 40.745301 48.423461 55.771988 63.820159 72.431918 90.695117
40.836723 35.211414 34.226893 35.480693 47.866784 54.764669 61.362372 68.340260 76.007307 90.650972
31.440060 28.552529 32.974314 47.310106 54.286326 60.884030 67.481735 74.079436 80.908525 90.606815
22.878165 25.299948 47.477846 53.807987 60.405690 67.003388 73.601098 80.198795 86.796504 93.476801
```
a

Water table map
```
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
91.887283 91.082626 92.327477 92.185699 92.043922 91.902153 91.760376 91.618599 91.476822 93.941223
85.237122 80.714005 77.147865 78.609055 78.070244 81.531425 82.327644 82.185867 85.792137 90.756889
78.158981 75.003265 71.188339 72.981796 74.156769 74.034210 73.896690 77.643051 82.607803 89.871727
71.080833 67.925125 63.776886 64.329491 65.671089 65.917755 72.675423 75.396019 79.423477 89.827576
64.002693 60.157753 53.988976 55.400520 56.812061 60.922096 67.546356 73.185043 76.239143 89.783432
56.924549 50.487541 45.057114 46.650551 47.547989 52.549683 59.542717 68.648476 73.054810 89.739273
48.550606 43.120178 37.689747 35.759315 39.745300 47.423462 54.771988 62.820160 71.431915 89.695114
39.836723 34.211414 33.226894 34.480694 46.866783 53.764668 60.362373 67.340263 75.007309 89.650970
30.440060 27.552528 31.974316 46.310104 53.286327 59.884029 66.481735 73.079437 79.908524 89.606812
21.878164 24.299948 46.477844 52.807987 59.405689 66.003387 72.601097 79.198792 85.796501 92.476799
```
b

Bed rock elevation map
```
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
89.887283 89.082626 90.327477 90.185699 90.043922 89.902153 89.760376 89.618599 89.476822 91.941223
83.237122 78.714005 75.147865 76.609055 78.070244 79.531425 80.327644 80.185867 83.792137 88.756889
76.158981 73.003265 69.188339 70.981796 72.156769 72.03421 71.89669 75.643051 80.607803 87.871727
69.080833 65.925125 61.776886 62.329491 63.671089 63.917755 70.675423 73.396019 77.423477 87.827576
62.002693 58.157753 51.988976 53.40052 54.812061 58.922096 65.546356 71.185043 74.239143 87.783432
54.924549 48.487541 43.057114 44.650551 45.547989 50.549683 57.542717 66.648476 71.05481 87.739273
46.550606 41.120178 35.689747 33.759315 37.745300 45.423462 52.771988 60.82016 69.431915 87.695114
37.836723 32.211414 31.226894 32.480694 44.866783 51.764668 58.362373 65.340263 73.007309 87.65097
28.44006 25.552528 29.974316 44.310104 51.286327 57.884029 64.481735 71.079437 77.908524 87.606812
19.878164 22.299948 44.477844 50.807987 57.405689 64.003387 70.601097 77.198792 83.796501 90.476799
```
c

Table 13. Grid pipe input file for Example 2.
```
GRIDPIPEFILE
PIPECELLS 5
CELLIJ 4 5
NUMPIPES 1
SPIPE 1 1 0.5
CELLIJ 5 5
NUMPIPES 2
SPIPE 1 1 0.5
SPIPE 3 1 0.5
CELLIJ 4 4
NUMPIPES 1
SPIPE 2 1 0.5
CELLIJ 5 4
NUMPIPES 3
SPIPE 2 1 0.5
SPIPE 3 1 0.5
SPIPE 4 1 0.5
CELLIJ 5 3
NUMPIPES 1
SPIPE 4 1 0.5
```

Figure 13. Flow into and out of tile drain network shown in Figure 11.
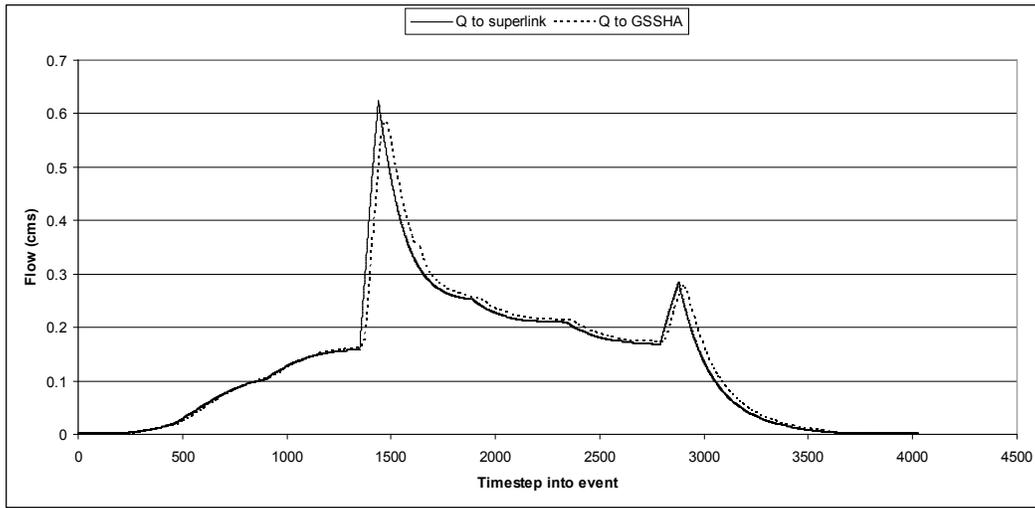
7   Summary

The new tile/storm drain network in GSSHA is computed through a scheme called SUPERLINK. The addition of SUPERLINK to GSSHA represents a major advancement in U.S. Army Corps of Engineers urban and agricultural hydrologic modeling capability. A SUPERLINK network consists of a series of superlinks made up of one or more pipes. The superlinks are connected to other superlinks, the overland flow grid, and the stream network though the junctions. A superlink can consist of one pipe or several pipes connected with nodes. To define the input of the tile/storm drain network, there are two new input files: the storm pipe network file, which describes the network and its attributes, and the grid pipe file, which describes the relation between the SUPERLINK network and the GSSHA grid. These two files are analogous to the channel input file and the grid stream file for the stream network. Storm drains may also function as tile drains as long as saturated groundwater is being simulated in the GSSHA model. The input requirements for storm drains and tile drains are the same; only the value of hydraulic conductivity for the pipe differs between storm and tile drains. When using SUPERLINK, GSSHA automatically writes a summary file for SUPERLINK called superlink_flows.out. Additional point time-series output can be obtained at any junction or node.

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14. ABSTRACT
The U.S. Army Corps of Engineers Gridded Surface Subsurface Hydrologic Analysis Model (GSSHA) is a physics-based, fully distributed, hydrologic model used for hydrologic and watershed analysis. The GSSHA model can operate on individual events or continuously with calculated evapotranspiration and soil-moisture accounting between rainfall events. GSSHA is applicable to a wide range of engineering and environmental problems, such as flooding, flood control, erosion and erosion control, and total maximum daily loadings and pollution abatement. A subsurface storm drain model, called SUPERLINK, has been incorporated into GSSHA to allow the model to explicitly include the effects of subsurface drainage networks. Representing subsurface drainage networks as channel, overland flow, or within the groundwater parameters can lead to significant errors when simulating watersheds with subsurface drainage features. In SUPERLINK, as implemented in GSSHA, flow to the subsurface system can originate from surface openings or subsurface tile drains. In agricultural settings, tile drains are used to lower the local water table below the crop root depth and exert a dominate influence on hydrology in these settings. This document briefly describes the SUPERLINK model and the inputs for a GSSHA model with SUPERLINK in detail.

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