WAM Calibration for the Lake Okeechobee Watershed

Deliverable #7: Enhancement and Extension of Load Estimation Tool

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Introduction

The Florida Department of Environmental Protection (FDEP) developed a Load Estimation Tool (LET) for the northern Lake Okeechobee BMAP sub-watersheds in 2014 that provides both the spatial total nitrogen (TN) and total phosphorus (TP) source loads as well as how much of these loads will ultimately reach Lake Okeechobee. The purpose of the tool is to provide agencies and private consultants with the ability to evaluate the relative benefits of various projects or BMP implementation programs based on their location within the watershed. The LET was developed for the northern six sub-watersheds based on the 2012 WAM model outputs and therefore did not include the three southern sub-watersheds. It also did not have the ability to separate the surface versus groundwater flows through the watershed stream network to their associated outlet locations into Lake Okeechobee. Therefore, the objective of this deliverable was to enhance the LET to provide separate estimates of N and P loads for both surface and groundwater at the source cells, after attenuation to the nearest stream/reach, and finally the loads from the source cell that ultimately reach Lake Okeechobee. The updated LET for the three southern sub-watersheds was presented in the March 17, 2017 draft report for deliverable #7. This report was reviewed and the methodology accepted by the Coordinating Agencies, therefore this report presents the updated LET for all the Lake Okeechobee sub-watersheds (six northern and three southern).

The existing FDEP LET is provided as an ArcMap polygon shapefile of land use that has six additional attributes added. These additional attributes are: TN and TP annual average loads being generated at the source cell, estimates of the amount of these source loads that will reach Lake Okeechobee, and finally the TN and TP attenuation factors between its source and Lake Okeechobee. The attenuation factors through the flow conveyance network was calculated as the source load minus the load reaching the lake divided by the source load. The existing LET does not distinguish between runoff and groundwater because groundwater attenuated loads to the nearest reach were not known at the time.

Enhanced Load Estimation Tool Development Process

To enhance the resolution of LET while providing load estimates for both surface runoff (RO) and groundwater (GW) discharges, it was decided that a grid-based tool would be more functional than a single shapefile. In addition, a grid-based LET allows for in-stream attenuation processes to be better handled because the flow distance from each source cell to the nearest reach and then to the basin outlet can be determined. The flow charts in Figures 1 and 2 describe the development process for N and P, respectively, for the new LET. The annual average N and P loads being generated at the source cells, and how much of the particulate (often referred to as sediment) and soluble N and P loads that end up reaching the nearest stream reach are output by WAM as a series of grids. These grids are:

sedncel1 = annual average sediment bond N load leaving a source cell (kg/ha/yr)
sedpcel1 = annual average sediment bond P load leaving a source cell (kg/ha/yr)

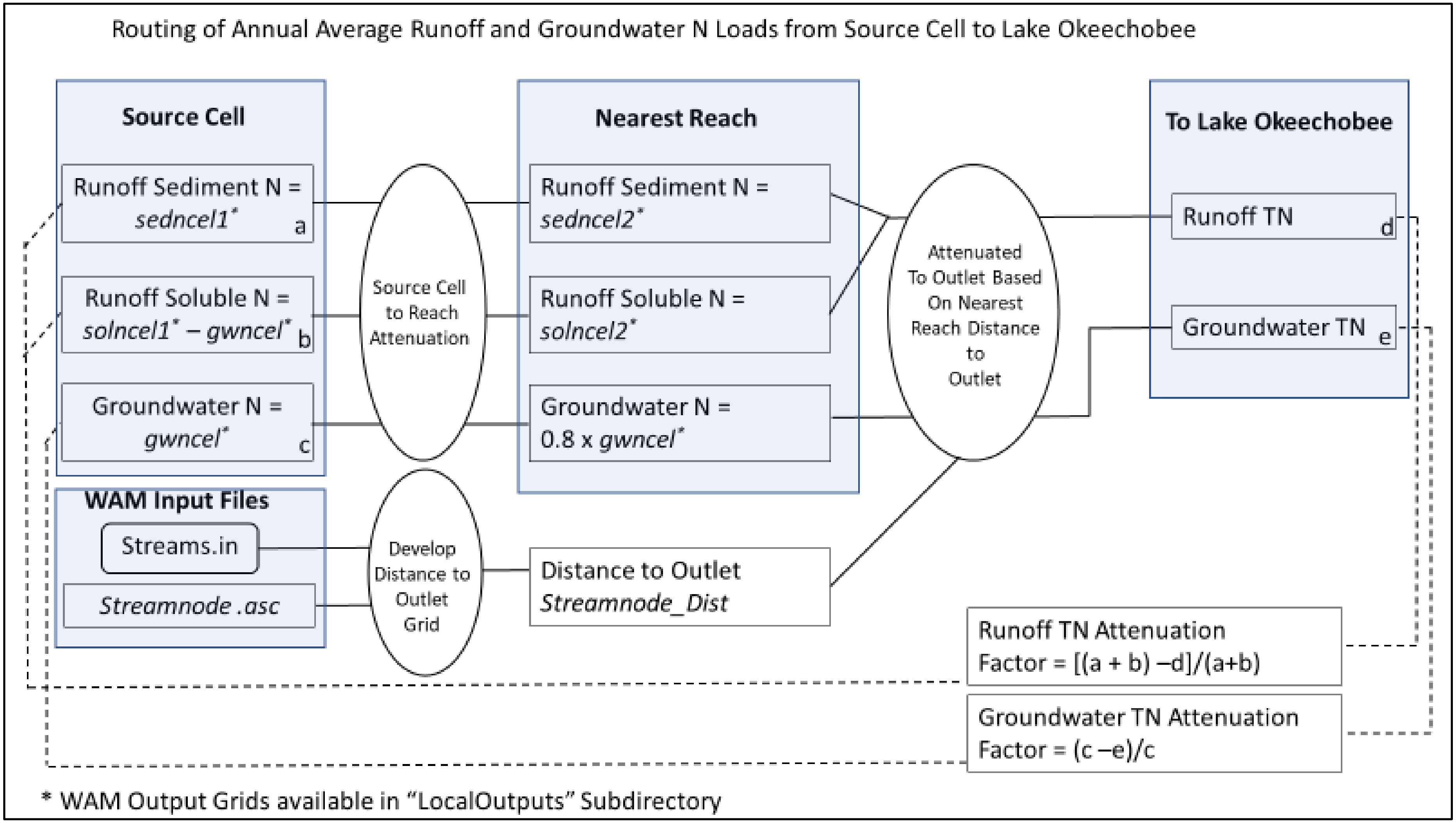

Figure 1. Development Flowchart for the LET Nitrogen Attenuation Processes from Source Cell to Lake Okeechobee

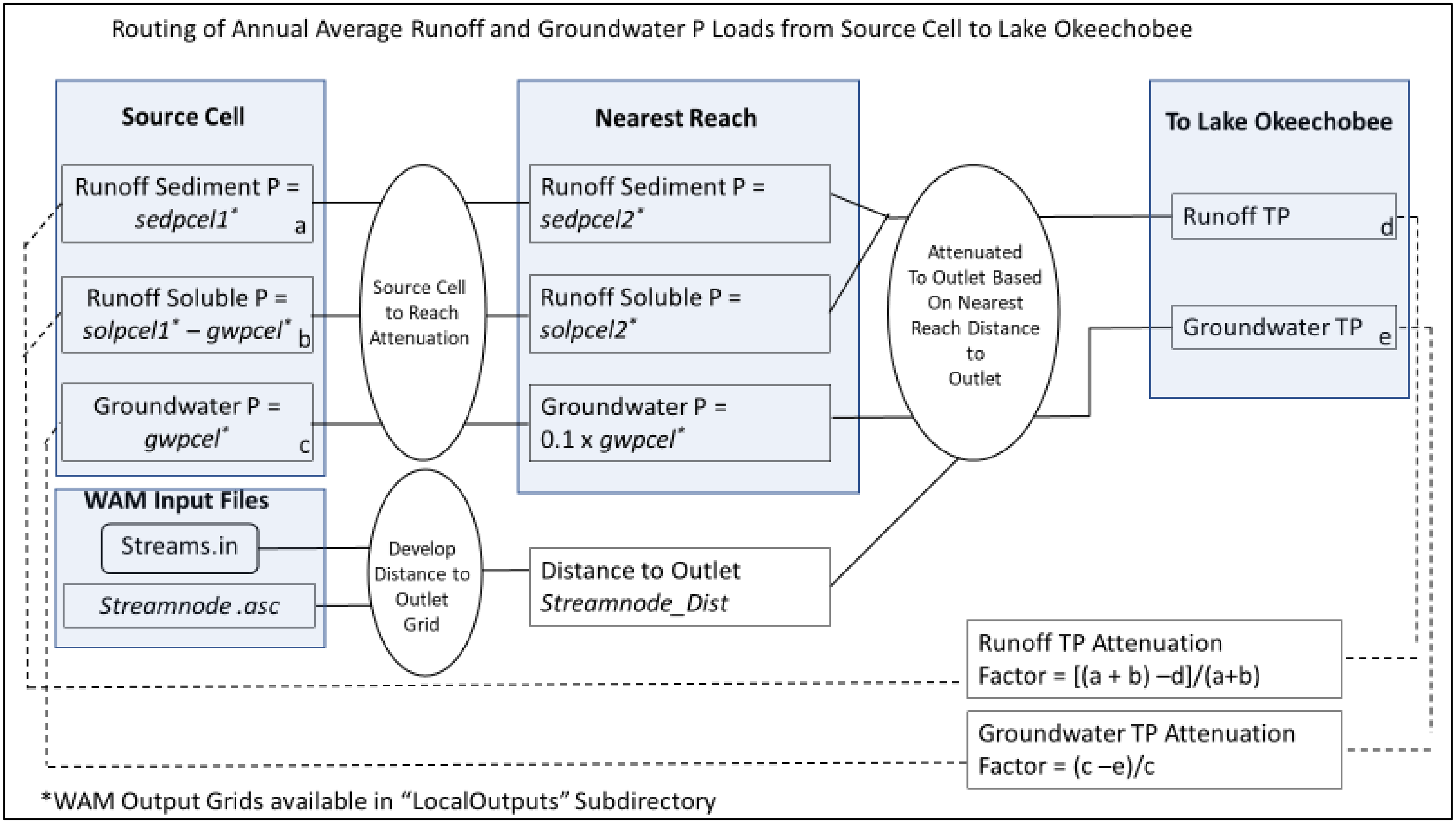

Figure 2. Development Flowchart for the LET Phosphorus Attenuation Processes from Source Cell to Lake Okeechobee

solncel1 = annual average soluble (RO + GW) N load leaving a source cell (kg/ha/yr)
solpcel1 = annual average soluble (RO + GW) P load leaving a source cell (kg/ha/yr)
gwncel = annual average soluble GW N load leaving a source cell (kg/ha/yr)
gwpcel = annual average soluble GW P load leaving a source cell (kg/ha/yr)
sedncel2 = annual average sediment bond N load to nearest stream reach (kg/ha/yr)
sedpcel2 = annual average sediment bond P load to nearest stream reach (kg/ha/yr)
solncel2 = annual average soluble (RO) N load to nearest stream reach (kg/ha/yr)
solpcel2 = annual average soluble (RO) P load to nearest stream reach (kg/ha/yr)

The format of these WAM grids requires a simple conversion to produce grids containing N and P loads separately for RO and GW, which is the first step shown in Figures 1 and 2. To obtain the RO and GW fractions of attenuated loads to the streams the following algorithm must be applied, which is based on WAM's known internal N and P attenuation factors of 0.8 for N and 0.1 for P for groundwater flowing from the source cell to the nearest stream reach. Therefore, as shown in Figures 1 and 2, using these known attenuation factors for GW flows to the nearest stream reach, grids of attenuated N and P loads can be calculated for both RO and GW flows as:

RO N grid (source cell) = solncel1 + sedncel1 - gwncel
RO P grid (source cell) = solpcel1 + sedpcel1 - gwpcel
RO N grid (to nearest reach) = solncel2 + sedncel2
RO P grid (to nearest reach) = solpcel2 + sedpcel2
GW N grid (source cell) = gwncel
GW P grid (source cell) = gwpcel
GW N grid (to nearest reach) = 0.8 x gwncel
GW P grid (to nearest reach) = 0.1 x gwpcel

The next step is to determine the flow distance from the source cell's receiving reach to the sub-watershed outlet going to Lake Okeechobee. This is accomplished by using the *streams.in* WAM input file that contains the next-down reach and split-reach stream routing information as well as the reach length information. An EXCEL spreadsheet program *Router.xlsx*, which uses the *streams.in* file to determine the downstream flow path and stream length for every reach on the way to the outlet. Some user input is needed at flow splits, which can direct flow to two different outlets, to be sure the distance is being properly calculated. This EXCEL program creates a grid that contains the flow distance in meters for every source cell's receiving reach to its appropriate outlet going to Lake Okeechobee. Note that only the outlets going into Lake Okeechobee are used for determining routing distances, but since a sub-watershed can have multiple outlets to Lake Okeechobee the program also has the receiving outlet reach number assigned to every reach, thus defining the catchment area for the outlet reaches. The resulting distance grids are shown in Figures 3 through 11, for each modeled sub-watershed. These grids allow for independent routing of flows from each reach to its associated outlet reach. Note that the S352 sub-basin associated with the West Palm Beach canal does not discharge to Lake Okeechobee through the S352 structure, but does have the remote possibility that stormwater generated within this sub-basin could reach the lake via the south cross canal and back up the Hillsboro canal to the S2 pump station. This remote possibility is accounted for by giving this S5A sub-basin very large distances to outlet. Also, some of the smaller discharges (C12A, C12, C4A, S236, and S310) into Lake Okeechobee were added to the larger discharge structures

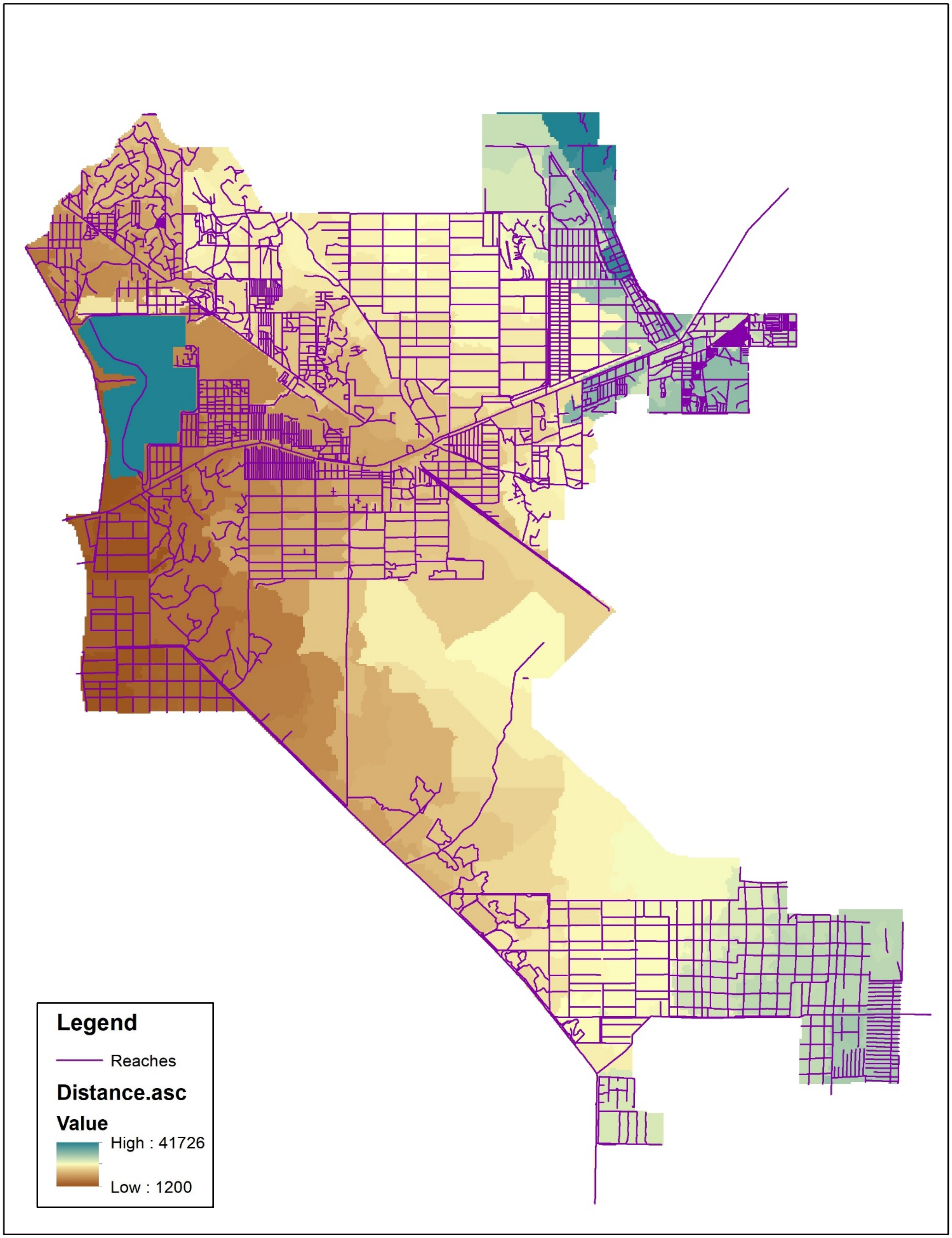

Figure 3. East Sub-watershed Flow Distance from Reaches to Lake Okeechobee

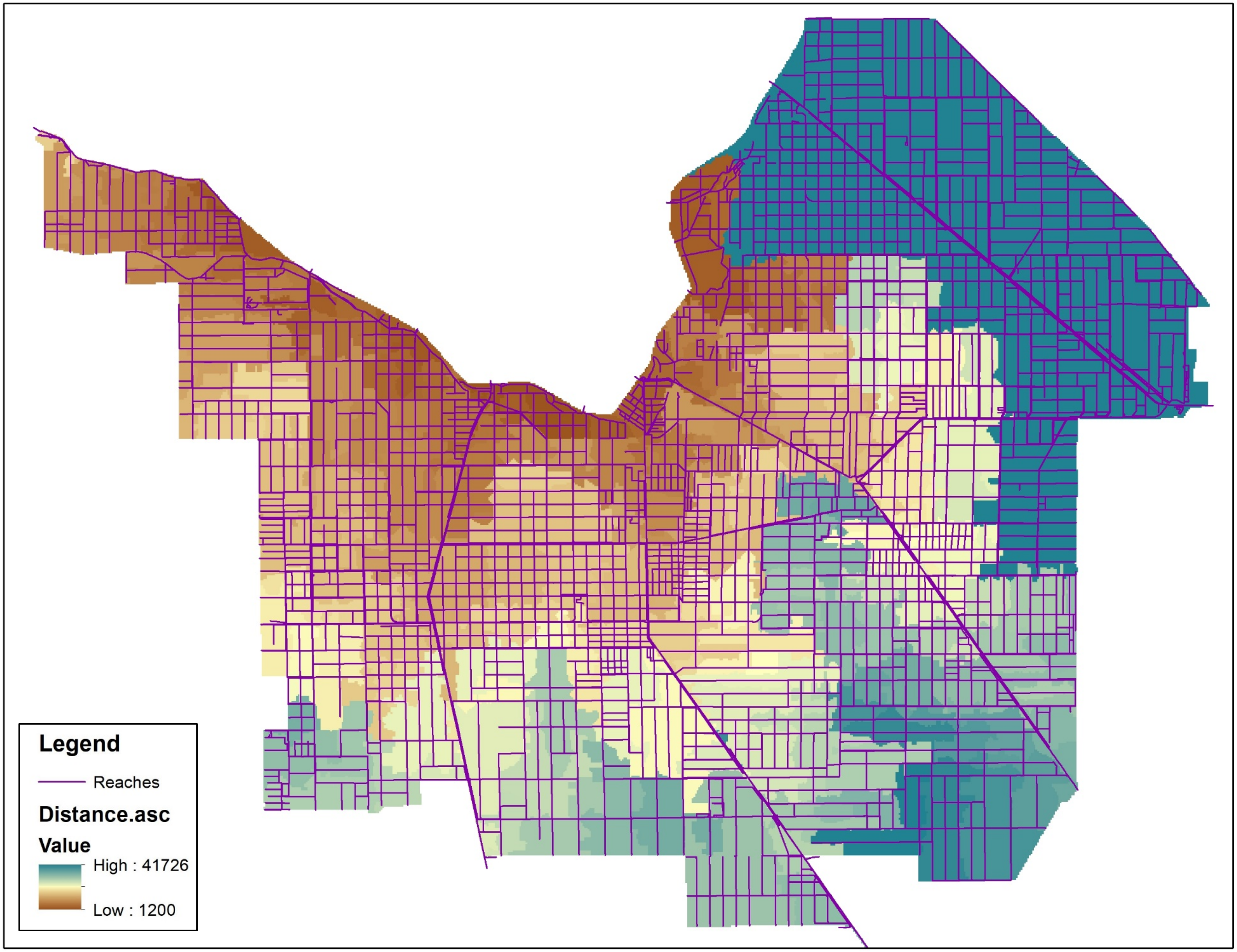

Figure 4. South Sub-watershed Flow Distance from Reaches to Lake Okeechobee

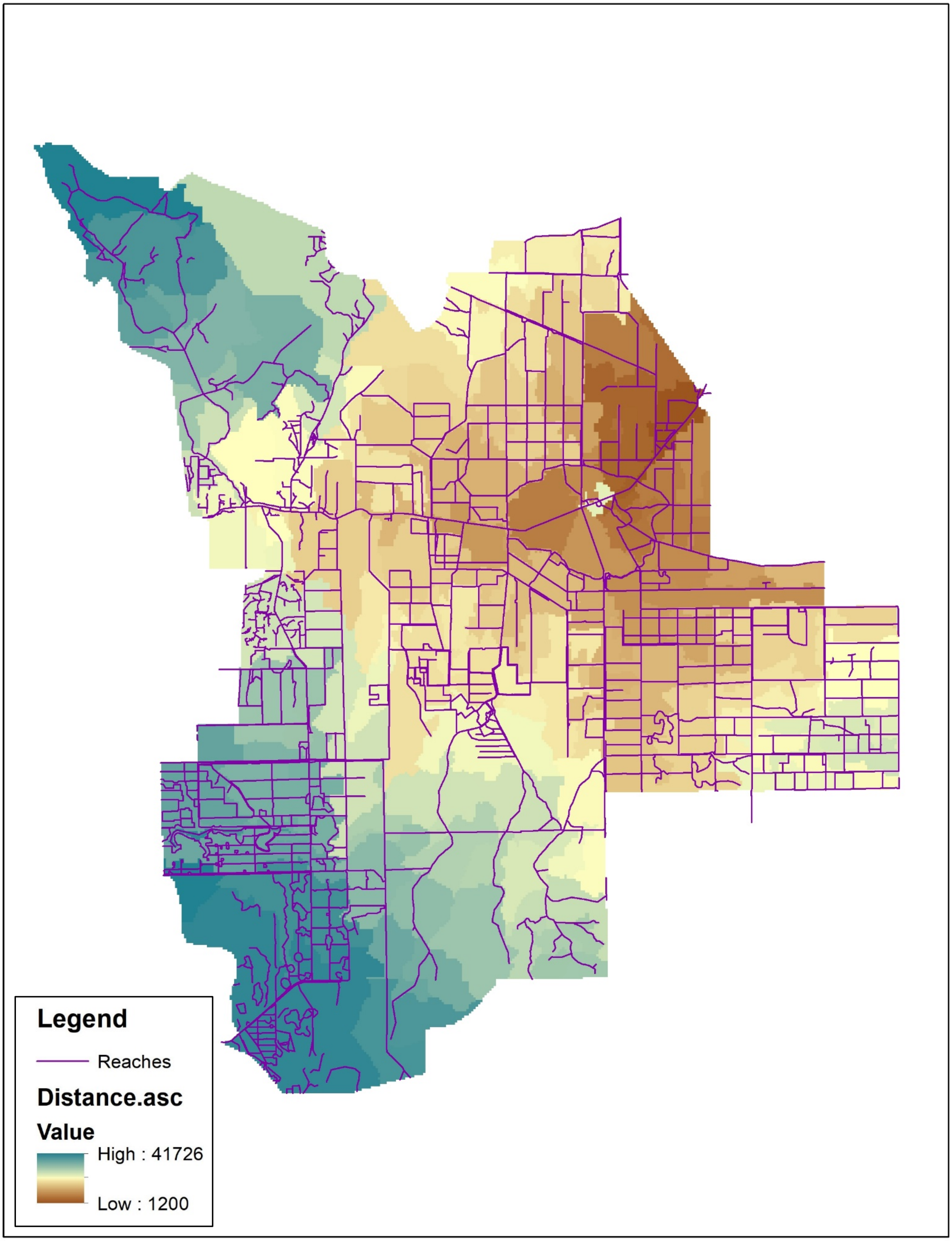

Figure 5. West Sub-watershed Flow Distance from Reaches to Lake Okeechobee

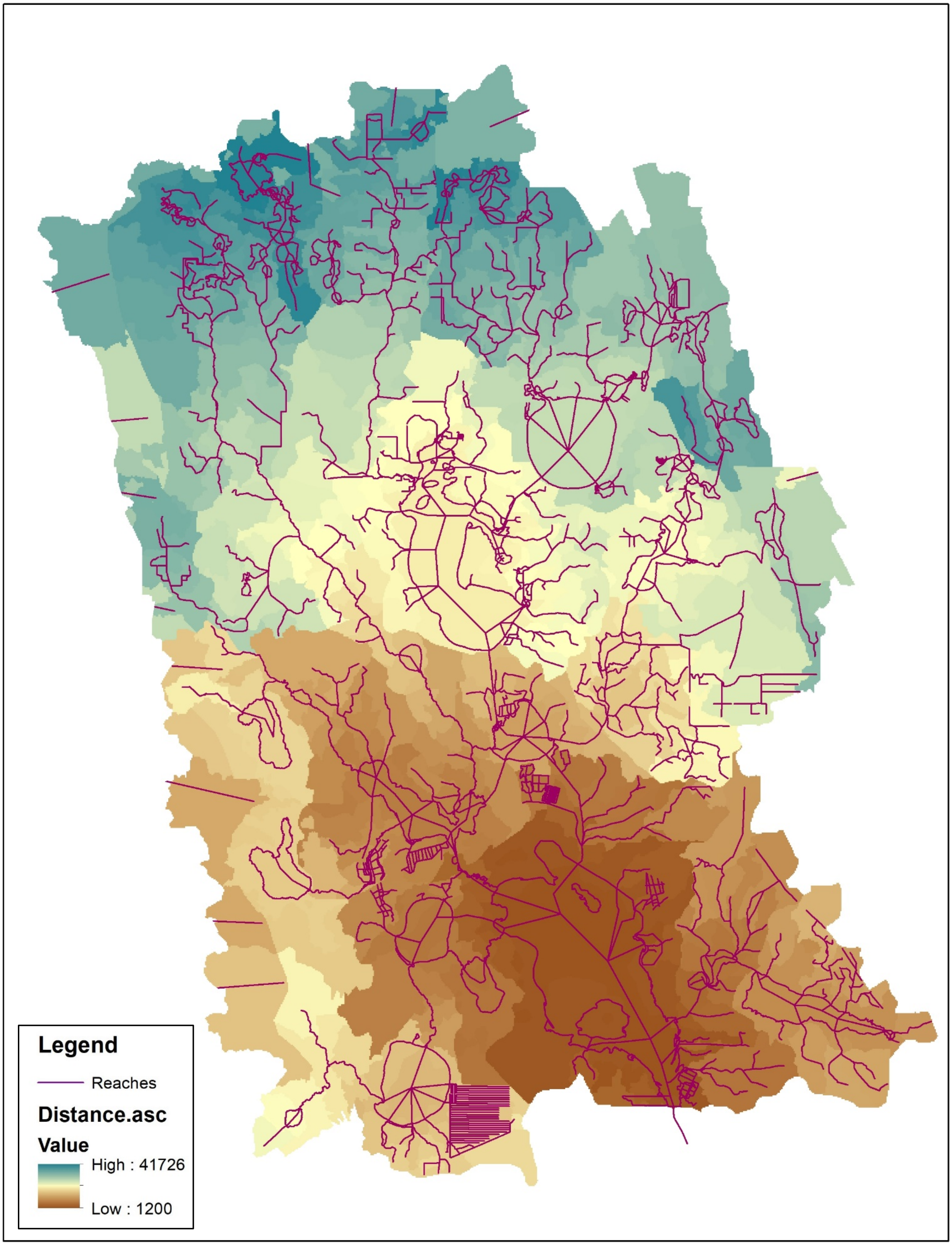

Figure 6. Upper Kissimmee Sub-watershed Flow Distance from Reaches to Lake Okeechobee

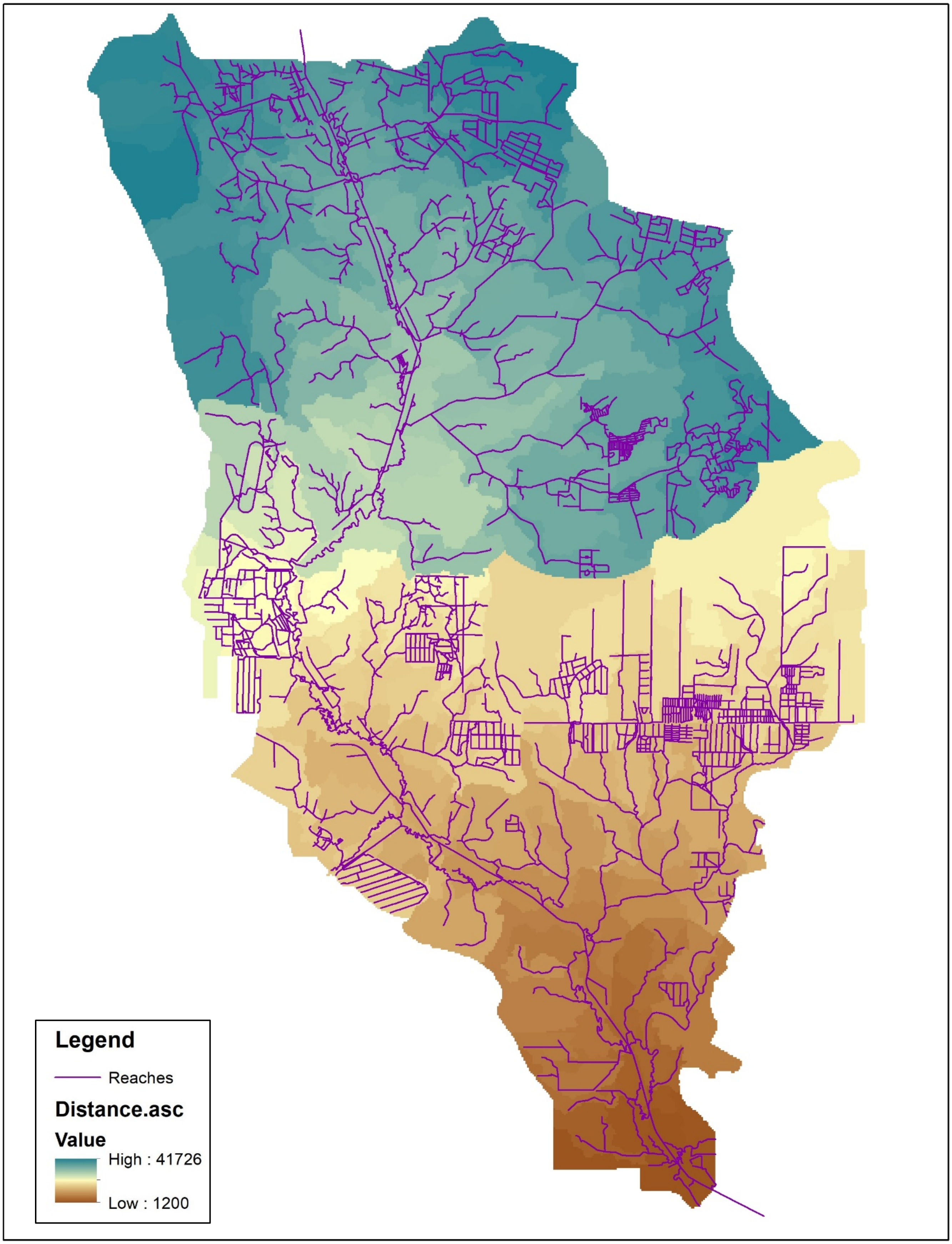

Figure 7. Lower Kissimmeee Sub-watershed Flow Distance from Reaches to Lake Okeechobee

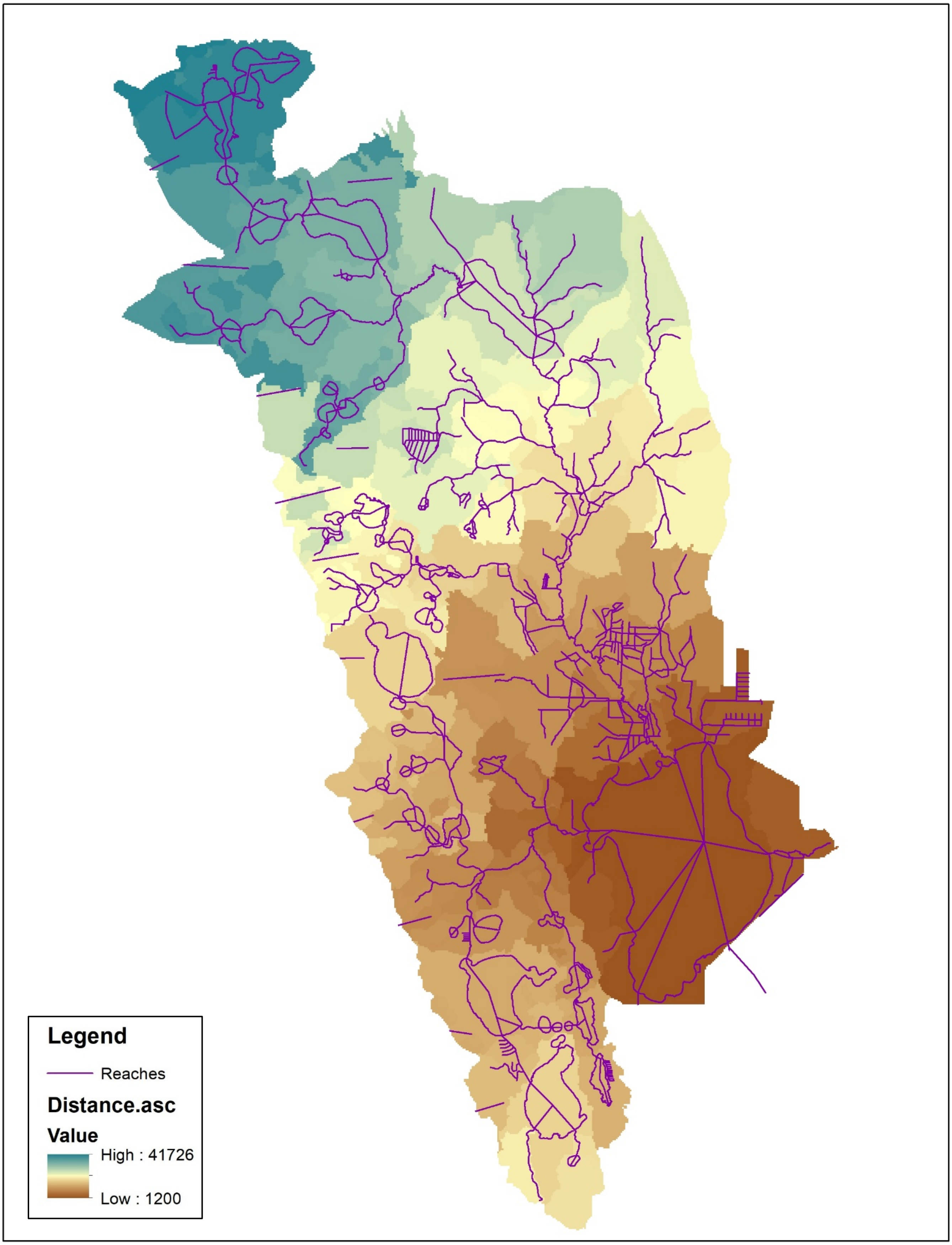

Figure 8. Lake Istokpoga Sub-watershed Flow Distance from Reaches to Lake Okeechobee

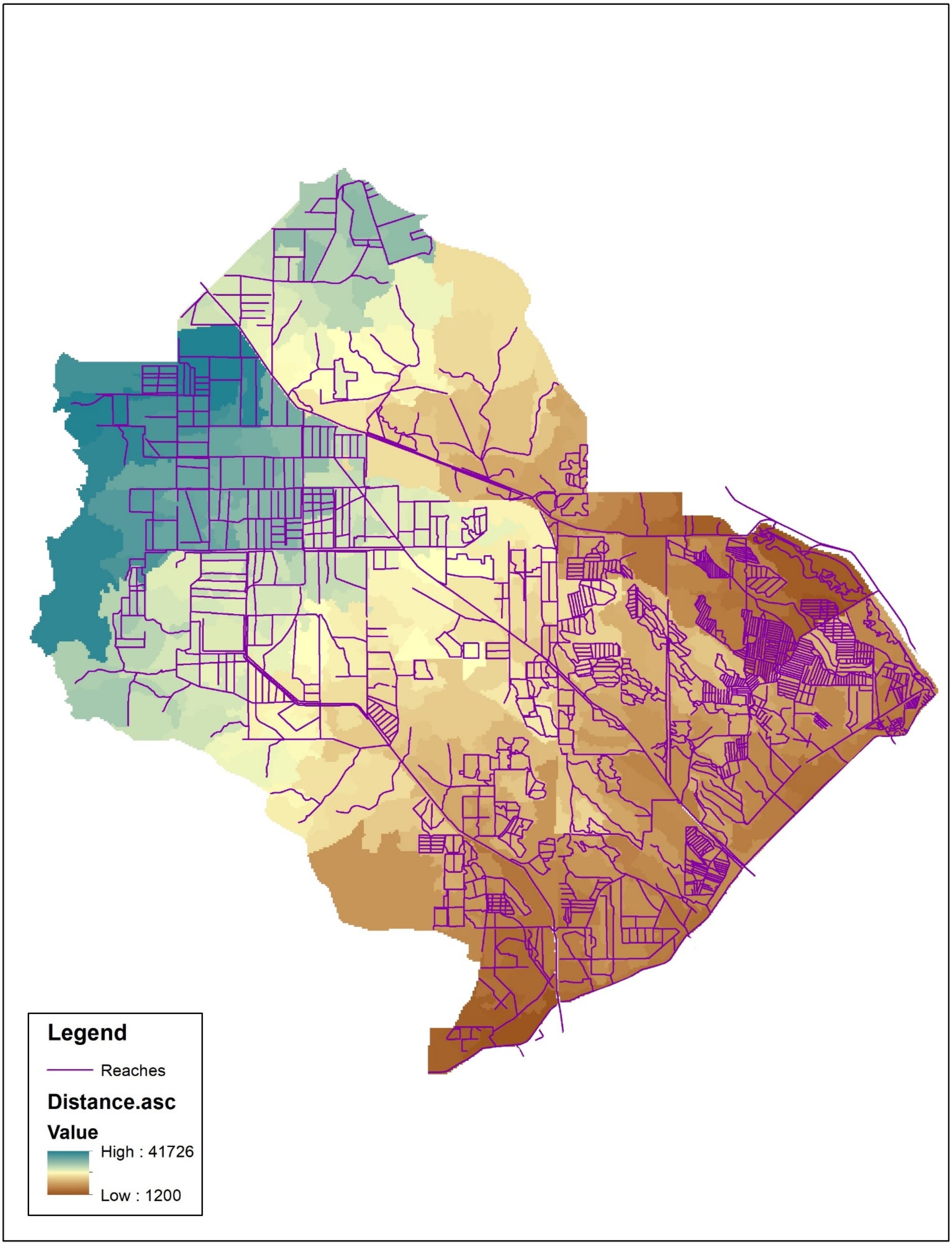

Figure 9. Indian Prairie Sub-watershed Flow Distance from Reaches to Lake Okeechobee

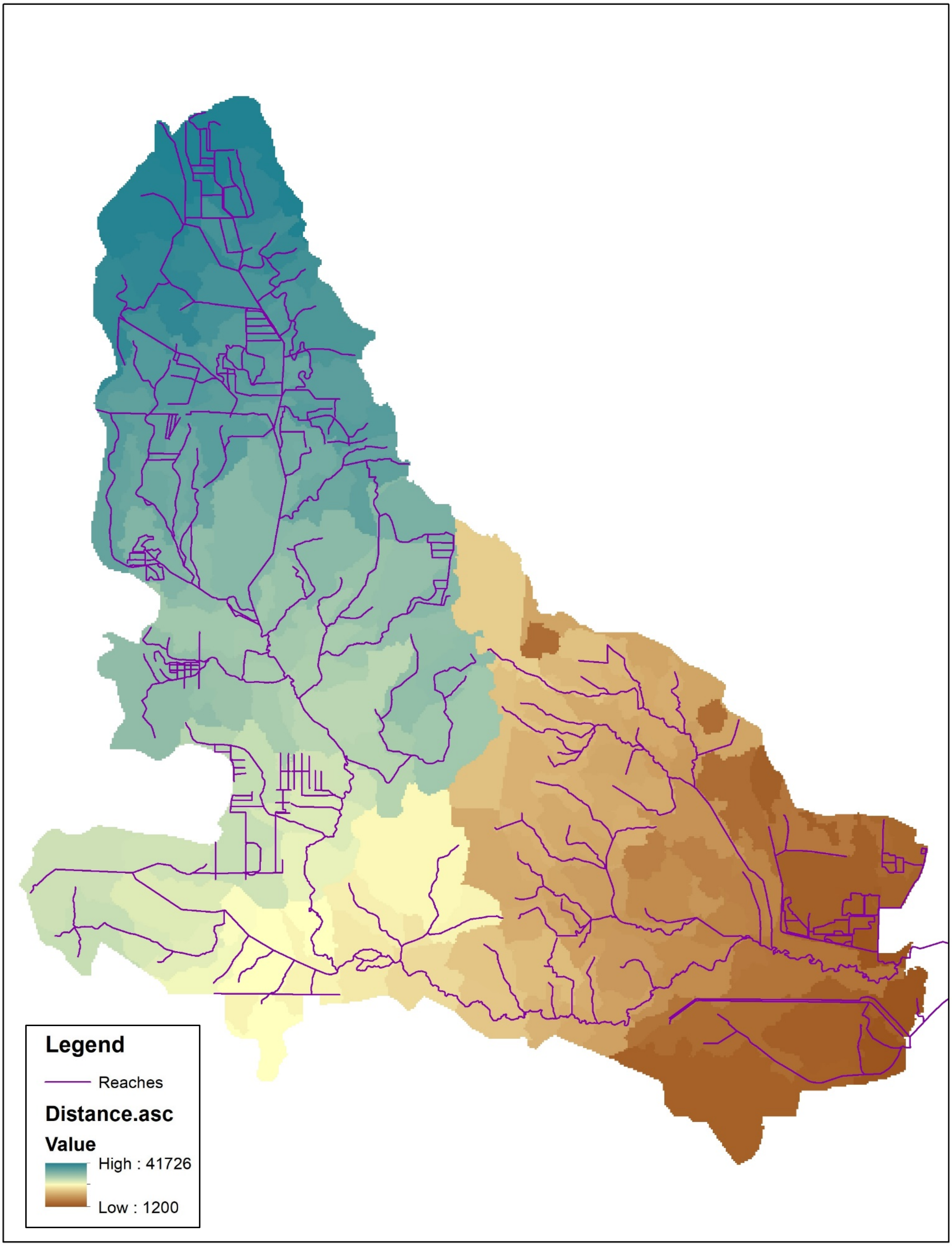

Figure 10. Fisheating Creek Sub-watershed Flow Distance from Reaches to Lake Okeechobee

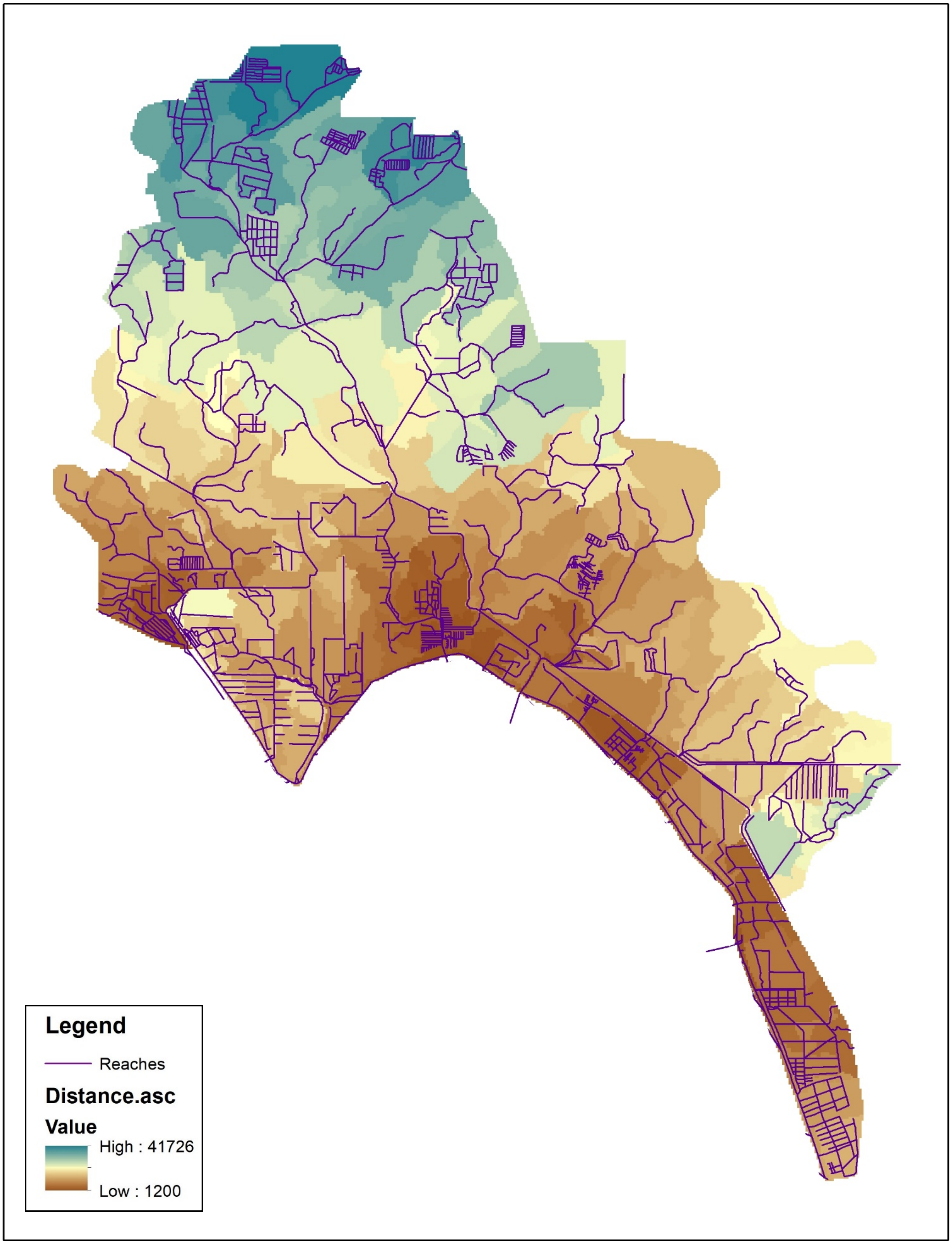

Figure 11. Taylor Creek / Nubbin Slough Sub-watershed Flow Distance from Reaches to Lake Okeechobee

to keep a complete mass balance, but the flow distances are determined for the actual distance to the smaller structures' lake discharge points. For example, the industrial canal discharges at S310 are represented in the S4 discharge, but distances within the S310 catchment are to the S310 lock. The distance grid within the *Streamnode_dist.xlsx* spreadsheet is then used by a series of EXCEL programs that attenuate the N and P loads reaching the stream reaches to the sub-watershed outlets by using the following attenuation algorithm commonly used for in-stream assimilation processes and is the original in-stream attenuation algorithm used by WAM before it was upgraded to a more robust wetted perimeter algorithm. The stream attenuation algorithm is defined as:

$$\text{Load at Outlet (kg/yr)} = L_r \times e^{-kD_n}$$

Where L_r (load to reach) is the TN or TP load in kg/yr entering reach #n from a source cell, k is the attenuation decay factor, and D_n is the distance (m) from reach #n to the outlet. Note that TN and TP loads are used for the in-stream attenuation processes because RO and GW flows are mixed once in the stream reach and therefore can no longer be distinguished as surface RO and GW sourced water. However, the relative contributions of RO and GW at the lake are generated based on the ratio of RO/GW flows reaching the nearest stream reach. This separation was done after the in-stream attenuation analysis was completed. The attenuation EXCEL programs, *AttenuatedLoadBalances.Rxx.xlsx,* for each outlet reach 'xx' allows the k factor for TN and TP to be adjusted independently until the simulated WAM TN and TP annual average loads at the outlet match the accumulated attenuated source cell TN and TP loads from the catchment area. Once the TN and TP loads for all the outlets have been matched, the final RO and GW LET grids are generated by recombining the individual catchment grids for each outlet into a sub-watershed wide grid. Note that these k factors also account for the fact that for some sub-watersheds a large percentage of the source loads do not discharge to Lake Okeechobee; instead they discharge to the coasts or to the conservation areas south of the EAA. For the southern sub-watersheds, only the S4 sub-basin has most of its catchment discharge going to the lake. All of the northern sub-watersheds discharge fully to Lake Okeechobee. Table 1 provides the calibrated k factors for the nine separate outlet catchments for the three southern sub-watersheds while Table 2 provides the calibrated k factors for the fourteen separate outlet catchments for the six northern sub-watersheds.

Table 1. Attenuation Exponential Decay Coefficients for the Southern Lake Okeechobee Sub-watershed Outlets

Outlet Structure	**Sub-watershed**	**"k" for TN**	**"k" for TP**
S308	East	-0.0000411	-0.0000332
C-11	East	-0.000021	-0.0000375
C-10A	East	-0.000051	-0.000082
S-352	South	-0.0000655	-0.0000655
C-10	South	-0.000013	-0.000237
S-2	South	-0.000008	-0.000099
S-3	South	-0.000013	-0.000237
S-4	South	-0.0000001	-0.000027
S-77	West	-0.000118	-0.000167

Table 2. Attenuation Exponential Decay Coefficients for the Northern Lake Okeechobee Sub-watershed Outlets

Outlet Structure	**Sub-watershed**	**“k” for TN**	**“k” for TP**
SR78	FEC	-0.0000043	-0.0000029
Culv5	FEC-Nicodemus	-0.0000158	-0.000005
S84,S71,S72,G34	Indian Prairie	-0.00000283	-0.0000027
S127	Indian Prairie-L47	-0.000019	-0.0000025
S129	Indian Prairie-L49	-0.0000001	-0.0000685
S131	Indian Prairie-L61	-0.0000905	-0.000108
S68	Lake Istokpoga	-0.0000238	-0.0000182
S65E	Lower Kissimmee	-0.0000149	-0.00000172
S191	TCNS	-0.0000096	-0.0000084
S154	TCNS	-0.000006	-0.0000064
S133	TCNS	-0.00000001	-0.000006
S135	TCNS	-0.00000001	-0.000043
Henry CK Lock	TCNS	-0.00106	-0.001275
S65	Upper Kissimmee	-0.0000114	-0.0000061

Grid and Shapefile Based Load Estimation Tool

The following grids were generated by the above described LET methodology for each sub-watershed and are available for input by ArcMap to evaluate source areas relative impacts on N and P loads into Lake Okeechobee for both surface RO and GW sourced flows:

RON_Source.asc = Annual average N loads (kg/ha/yr) leaving source cell in RO
GWN_Source.asc= Annual average N loads (kg/ha/yr) leaving source cell as GW recharge
RON_Reach.asc = Annual average N loads (kg/ha/yr) to nearest stream reach in RO
GWN_Reach.asc= Annual average N loads (kg/ha/yr) to nearest stream reach as GW
RON_Lake.asc = Annual average N loads (kg/ha/yr) entering Lake Okeechobee from RO
GWN_Lake.asc= Annual average N loads (kg/ha/yr) entering Lake Okeechobee from GW
ROP_Source.asc = Annual average P loads (kg/ha/yr) leaving source cell in RO
GWP_Source.asc= Annual average P loads (kg/ha/yr) leaving source cell as GW recharge
ROP_Reach.asc = Annual average P loads (kg/ha/yr) to nearest stream reach in RO
GWP_Reach.asc= Annual average P loads (kg/ha/yr) to nearest stream reach as GW
ROP_Lake.asc = Annual average P loads (kg/ha/yr) entering Lake Okeechobee from RO
GWP_Lake.asc= Annual average P loads (kg/ha/yr) entering Lake Okeechobee from GW
RON_Att_Rate.asc = Attenuation rate for RO N between source cell and Lake Okeechobee
GWN_Att_Rate.asc = Attenuation rate for GW N between source cell and Lake Okeechobee
ROP_Att_Rate.asc = Attenuation rate for RO P between source cell and Lake Okeechobee
GWP_Att_Rate.asc = Attenuation rate for GW P between source cell and Lake Okeechobee

The above grids are provided separately for each sub-watershed to minimize the size of the grids and with the understanding that most users would only be interested in using the LET for individual projects within a given sub-watershed. The source and lake loads grids have also been added as attributes to the land use shapefiles for each sub-watershed using the “Zonal Statistics to Table” tool in ArcMap, so shapefile versions are available that will function similar to the previous FDEP LET, however the presented grid-based LET format is believed to be much more robust.

The LET grids and feature classes (shapefiles) for the nine sub-watersheds are available for download using the following link:

ftp://anonymous_swet:swet@ftp.swet.com/FDACS/Load_Estimation_Tool.zip

Example Use of Grid-based LET

The advantage of the grid-based LET is that it has a one hectare resolution whereas the shapefile-based LET is limited by the size of the land use polygons in the original land use feature class. For example, some land use polygons can extend across several miles particularly for improved pasture and wetlands, which means the source and lake loads presented in the shapefile will be averages taken across fairly large areas. Therefore, the grid-based LET will provide more accurate estimates for all the LET parameters because only the loads for the grid cells within a project polygon will be used, which is accomplished using the “Zonal Statistics to Table” tool located under “Zonal” in the Spatial Analyst Tools menu in ArcMap. This tool will calculate the mean (other statistics, such max/min and standard deviation, are also available if desired) for any of LET grid values located within all polygons defined in a user generated feature class or shapefile. For example, if you have shapefile named “Projects.shp” that contains three polygons for potential alternative project sites, then Figure 13 shows how the zonal statistics tool can be used for obtaining the mean nitrogen source load in runoff for the three polygons (Figure 14). The same can be done for any of the LET grids to look up N and P loads from the source polygon, to the nearest stream reach, to the lake, or the attenuation factors for source loads to the lake. As can be seen, the resulting table shown in Figure 14 also contains the grid cells count, which correlates directly to area in hectares for each polygon, and an area column that has units of square feet.

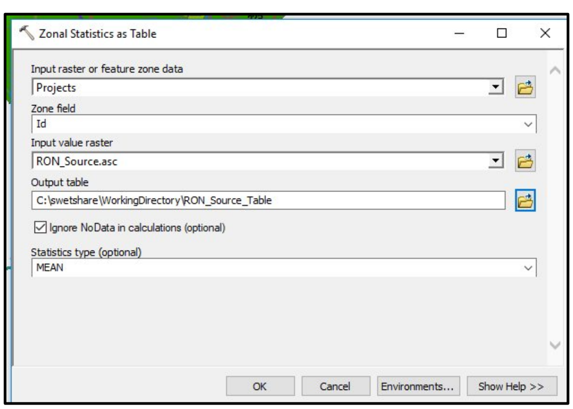

Figure 13. Example of the ArcMap “Zonal Statistics to Table” tool to calculate LET loads and attenuation factors

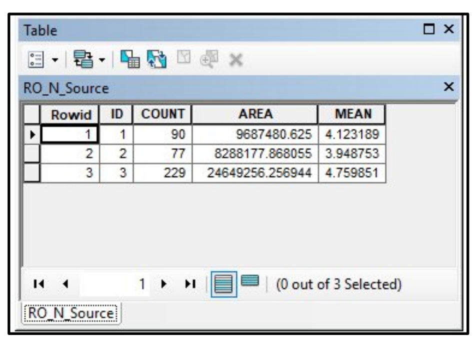

Figure 14. Example output table from the ArcMap “Zonal Statistics to Table” tool for annual average TN load leaving the polygon in runoff (RO)