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Developing Watershed Analysis Tool in GIS Environment

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ABSTRACT

The process of deriving the hydrological parameters in the GIS environment requires semi-automated procedures that depend on the user's experience with the tools designed within the system, and this in turn may cause technical errors as a result of implementing the sequential steps that address an issue, so there was a need to develop tools that depend on the total automated derivation reduce the number of steps while reducing the time required for implementation. As a result, in the presented work, a hydrological tool was created as an automated workflow using Python and ArcGIS Model Builder, which will be explained. The workflow for this tool was developed in Python and applied to Iraq's northeast region. Through the statistical comparison of all derived stream configuration results using DEM, an ideal threshold value was found to maximize drainage configuration. The code was successful in automatically estimating the right ranking of specified stream orders without any further manual processes. Therefore, the developed tool saves effort and time, making it an extremely valuable function for large catchment basins.

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تطوير ادوات للجابية المائية في بيئة نظم المعلومات الجغرافية

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الخلاصة:

تتطلب عملية اشتقاق المعالم الهيدرولوجية في بيئة نظم المعلومات الجغرافية اجراءات نصف آلية، مما يجعل استخدامها يعتمد على خبرة المستخدم مع العمل على برمجية ArcGIS desktop ، وهذا بدوره قد يؤدي الى اخطاء فنية نتيجة تنفيذ الخطوات المتسلسلة التي تعالج المشكلة، لذلك كانت هناك حاجة لتطوير الأدوات التي تعتمد على الاشتقاق الآلي الكلي لتقليل عدد الخطوات مع تقليل الوقت المطلوب

للتنفيذ. ولتحقيق ذلك، تم بناء أدوات باستخدام لغة Python والتطبيق ArcGIS Model Builder اللذان يعملان على تنفيذ العمل الآلي الكامل لاشتقاق المعالم الهيدرولوجية التي تم تطبيقها في منطقة شمال شرق العراق كما سيتم مناقشة ذلك في متن البحث. وقد نجح عمل الادوات المطورة في اشتقاق المعالم الهيدرولوجية دون عمليات نصف آلية تذكر، لذلك سوف توفر الادوات المطورة الوقت والجهد، مما يجعلها وظيفة قيمة للغاية في التعامل مع تحليل الاحواض المائية.

الكلمات المفتاحية: نظم المعلومات الجغرافية، دم، نموذج ArcGIS، بايثون

Introduction

When developing certain tools in the GIS environment, and in general, this requires achieving two important questions, first of which is to achieve the feasibility of the developed technology, which must be more efficient than the original tool in terms of speed of implementation and ease of use, and the second is to achieve spatial feasibility, which ensures that the outputs are at least identical with original tool output. Various factors influence the development of the watershed systems across time and space, including tectonic lineaments, lithology, soil, geomorphology, and area's land cover (Yahya, 2019; Khan et al., 2021). A lot of such factors are reflected in the landscape's topography, which could be classified and quantified with the use of geomorphological concepts. Watershed analysis in a geographical information system environment (GISE) is defined as the process of delineating watersheds and determining properties like stream networks, streams, basin boundaries, catchment regions, and so on utilizing digital elevation model (DEM) and raster data operations (Irarrazaval et al. 2021; Ghosh, and Gope 2021). Watershed boundaries are conventionally created manually on a topographic map. In order to identify where a divide is located, an individual who draws boundaries utilizes topographic elements on map. Things have grown considerably easier since the emergence of computers (Yin et al. 2021). In comparison to the conventional approach, preliminary watershed boundaries could currently be generated in a fraction of the time. A thorough morphometric analysis regarding a basin could substantially aid in determining the effect of drainage morphometric analysis on landforms and their characteristics (Bogale, 2021). In addition, morphometric analyses are critical in the estimate of a variety of hydrological phenomena, such as flash flood risk and rainwater harvesting, to name a few. Which is why, results of the morphometric analyses will be an important component of a detailed water resource management approach (Esin *etal*., 2001; Al-neama *etal*., 2022).

Hydrological models are primarily depending on morphometric characteristics, which necessitate the definition of both watershed lines and drainage networks, and were used to remote basins in semi-arid and arid areas. As a result, state-of-the-art approaches must be used. Those include the use of Geographic Information Systems (GIS) to analyse Remote

Sensing (RS) data, as well as the availability of the high-resolution DEMs from the satellites of earth observation and advances in the fields of the computer science.

There are many published scientific papers whose researchers have been able to design tools that can be interconnected with the GIS environment. These tools have been used to address various geographic, geological and environmental problems that GIS programs cannot solve or require several steps or more time to address, while the developed tools provide Quick and practical solutions at the same time. Among these researches is what was presented by each of Xiaoyong Zhan and Min-Lang Huang in 2004 were an Arc GIS tool named ArcCN-Runoff was developed and used for the generation of the curve number, runoff maps and the infiltration from rainfall events in the watershed. In the year 2009, Jimenez-Peralvarez et al. have presented a study in ArcGIS on developing models for the automatic landslide susceptibility analysis, validation, and mapping. In the presented work, Model Builder in ArcGIS (ESRI) was used to do landslide susceptibility analysis. Brown created SDM-toolbox, a python-based GIS toolkit for the landscape genetic, bio-geographic, and species distribution model (SDM) investigations, in April of 2014. SDM-toolbox is a free, complete python-based tool-box for the macro-ecology, landscape genetics, and evolutionary researches that could be utilized with spatial analyst extensions in ArcGIS 10.1 (or higher). Various GIS analyses that are needed for the species distribution modelling as well as other analyses are simplified by the toolkit, eliminating the requirement for time-consuming climate data preprocessing and post-SDM analyses. Italian Aerospace Research Center (IARC) had developed Meteorological Aviation Supporting System (MATISSE), which is an ArcGIS Desktop Plug-in that is capable of detecting and forecasting meteorological aviation hazards over the European airports utilizing various meteorological data sources (such as synoptic information, satellite data, numerical weather prediction model data). MATISSE provides GUI that allows the user for selecting and visualizing these meteorological conditions over a certain airport or area. Various techniques are also implemented in the system for now-casting the meteorological hazards as well as the statistical characterizations of the typical adverse conditions of the weather for the chosen airport (Rillo ET AL., 2015).

In this study an implemented automated workflow that is based upon ArcGIS Spatial Analyst tool-box that was enriched by the Python scripts for the extraction of the stream network from the DEM with the stream segmentations based on shirf and Strahler's theory. This model runs in batch for the purpose of producing various drainage network configurations through the iteration over a broad variety of the thresholds.

Study area description

Iraq is one of the richest countries in the region with its great water wealth, and the most important sources of this wealth are the rivers, where six international rivers pass through its lands, namely the Tigris, the Euphrates, the Upper Zarb, the Lower Zab and Khabur river. This study was conducted on Upper Zarb and Lower Zab basins where they can be briefly described as follows as seen in Fig. 1.

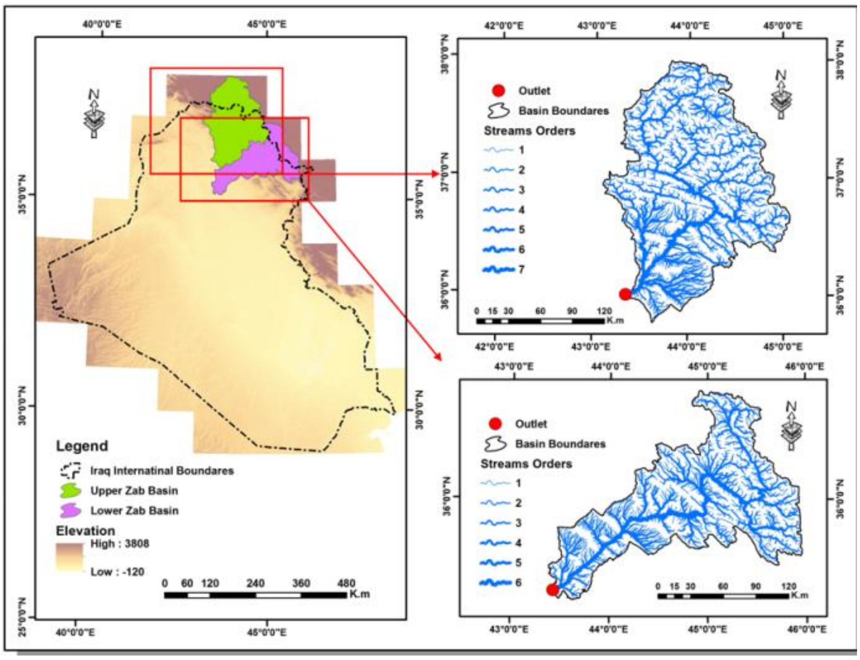

Figure1: geographical location of the area of this study

With a 372 km length, the Greater Zab originates in Turkey and travels through it and the center northern section of Iraq before joining Tigris River south of Mosul. The greater Zab is located between 36N and 38N latitude and 43.3E and 44.3E longitude. It drains a total area of 26,473 km2, with 65% in Iraq and the remainder in Turkey. Lower Zab (which is sometimes referred to as Lesser Lower Zab as well) rises in Iran's northeastern Zagros Mountains and flows across Iraq and Iran for 302 kilometers before joining the Tigris River at Fatah (south of Mosul city). Watershed lies between 35.16 N and 36.79 N latitude and 43.39 E and 46.26 E longitude. Lesser Zab covers a total area of 15,600 km2, with 80% of it in Iraq and the rest in Iran. The climate in Greater and Lesser Zab watersheds is arid to semi-arid, with rainy winters and hot, dry summers. The average yearly temperature degree varies between 22 degrees Celsius in the south and 10 degrees Celsius in the north. The yearly rainfalls averages 1500mm in the north and 350mm in the south mm. The flow regimes of the Lesser and Greater Zabs are very seasonal, with the occurrence of the peak flow between April and May because of snow-melt and low seasonal flows occur between the months of July and December. Approximately 70% of catchment is covered by the pasture, with the remainder being used for the agricultural applications.

Data used

It is important to have a digital database in raster and table dataset format in order to use any GIS software in the develop tools procedure. A DEM was utilized for extracting morphological data for every sub-basin in the study area, which was then converted into morphometric parameters. The DEM represents rasterized digital representation regarding cartographic data derived from terrain elevation data. The Land Processes Distributed Active Archive Center (LP DAAC) of National Aeronautics and Space Administration (NASA) was used to collect data from the Advanced Spaceborne Thermal

Emission and Reflection Radiometer (ASTER) Global DEM V. 2 (ASTER GDEM) of Wadi Greater Zab Basin and Lower Zab Basin. The ASTER GDEM is available in Geo TIFF format containing geographic coordinates of latitude/longitude at 12.5 m resolution grid of elevation postings from Earth Observing System Data and Information System (EOSDIS, 2020). In October of 2020, the DEM was made available for download. The research area's GDEM data was converted to projections of the Universal Transverse Mercator (UTM) zone 36 (WGS84).

An overview of the Hydrology toolset in GIS environment

The ArcGIS Spatial Analyst extension toolbox's hydrologic modeling capabilities give approaches for defining the surface's physical components. Determine flow direction, identify sinks, delineate watersheds, compute flow accumulation, and create stream networks with the hydrologic tools. The installed Hydrology extension toolbox in any version of Arc Gis software utilized for modeling the flow of water contains hydrologic analysis functions which visualized the water across surface, concepts and key terms concerning the systems of drainage and surface processes, and the way that tools may be utilized for the extraction of the hydrologic information from a DEM.

1- Understanding drainage systems

The drainage basin represents an area which drains the water as well as other substances to some shared outlet. It is also known as a basin, watershed, catchment, or contributing area. The total area flowing to a specific outlet is generally specified as this area. Any superficial drainage network would like to contain valley streams that intersect at certain points and as a result of this intersection, another stream of a higher rank is formed, these streams were classified according to certain classifications (Strahler, 1964) so on until the main stream with a higher rank is reached, and the last point is called the downstream outlet.

2- Exploring DEMs

Cell-based DEMs are the most popular digitized data about geometry of earth's surface. This data is utilized to calculate the properties of land surface. In addition, a DEM can be defined as a raster representation regarding continuous surface, most commonly the earth's surface. The resolution (i.e. distance between points of the sample) determines the accuracy of this data. The data format (integer or floating point) and actual sampling regarding the surface in the case of constructing original DEM.

3- Deriving runoff characteristics

When delineating watersheds or stream networks, there are several procedures that can be taken. Based on the features of the supplied data, some stages are obligatory while others are optional. Flow will often be in steepest downslope direction across a surface. There is a possibility to tell which and how many cells are flowing into any particular cell as soon as direction of flow out of every one of the cells is known. The watershed boundaries and stream networks might be defined with the use of this data.

4-Creating a depression less DEM

The flow direction technique requires DEM that is free of sinks—a depression-less DEM. If sinks are present, the flow-direction raster might be incorrect. There could be legitimate sinks in the data in some conditions. It is a high necessity in having a thorough understanding of area's morphology so as to determine which features are true sinks on the earth's surface and which are simply data errors. The capabilities in the ArcGIS Spatial Analyst Extension's Hydrology toolset can help in creating a depression-less elevation surface.

5- Creating watersheds

The upslope area of a watershed contributes flow—in general, water—to some shared outlet as concentrated drainage. It might be a part of larger watershed and could be containing smaller watersheds, which are referred to as sub-basins. Drainage divides are boundaries between the watersheds. The outlet, also known as the pour point, is the point on surface when water flows an area. It's the lowest point on a watershed's boundary. Through determining flow direction and utilizing it in Watershed tool, watersheds could be identified from a DEM. To identify the contributing area, use the Flow Direction tool to build a raster reflecting the flow direction. One must next specify the locations for which you want to determine the catchment area. One might want to specify the properties of the contributing area at source locations like stream gauges or dams. A flow accumulation threshold could also be used. The watershed's pour points will be junctions of stream network that is formed from flow accumulations in the case when the threshold is utilized to define it. As a result, a flow accumulation raster along with the minimal number of the cells which make up a stream (i.e. threshold value) should be defined.

Methodology

ArcGIS Spatial Analyst includes specialized tools for working with hydrologic and landscape data and extracting new information. It has techniques for expressing hydrologic properties, as well as tools for calculating flow across an elevation surface, calculating flow path length, and assigning stream orders. Those types of derived data are frequently utilized to combine landscape data for use in hydrologic models. The method for processing a DEM to permit interactive watershed delineation and stream network extraction is presented in this work, which includes three key procedures: speed run, save time, and fully automated processes. The stream network and basin delineation criteria and steps will be clearly depicted. Workflow has been created using tools from ArcGIS 10.8 toolbox, specifically from spatial analyst extension. For batch processing, the different tools were integrated with the use of ArcGIS Model Builder. Because the Model Builder is still lacking in its ability to implement loops as a tool in ArcGIS, the models were supported by prepared scripts and Python codes. The steps are as follows, as shown in Figure 2 of the flowchart.

First, the raster elevation to stream orders tool was four steps that must be achieved in order to obtain information with this tool as follows and as seen in Figure 3.

1- Input elevation raster parameter, from which the raster file is entered.

2- Expression coefficient, from which the details of the waterways are determined.

3- The method of stream ordering parameter, from which the method of arranging the waterways is determined. The laboratories have two options, one of which is concerned with arranging the waterways by the Sherif method and the other by the Strehler method which available in ArcGIS Sofware.

in ArcGIS.

4- The parameter Output stream orders, from which the outputs are saved in the computer memory in vector format.

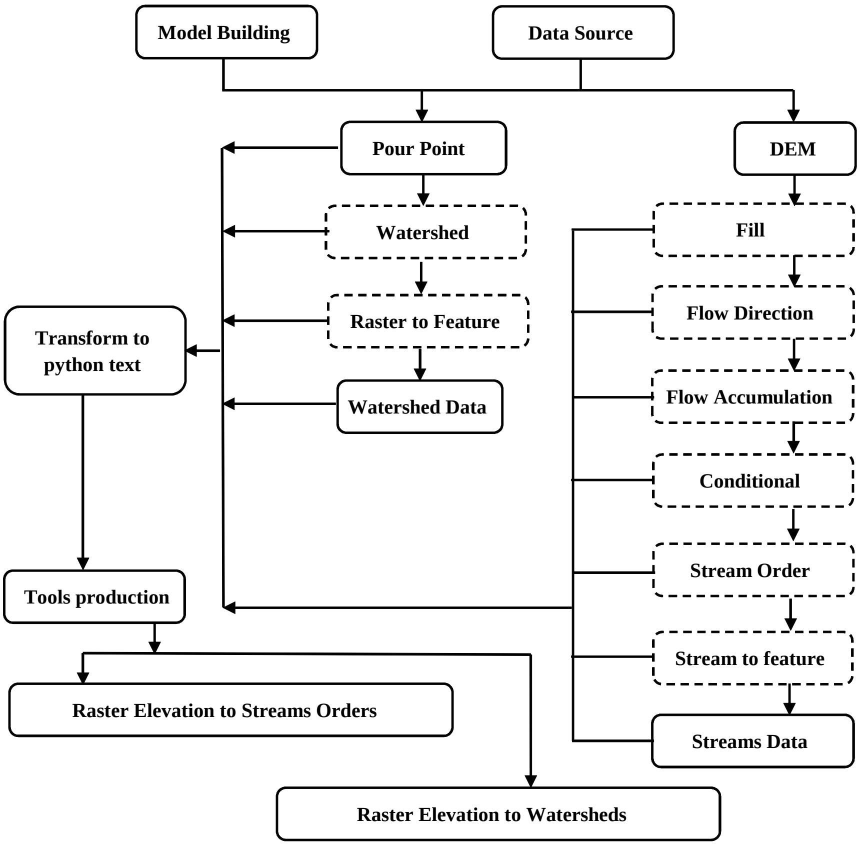

Figure 2: the flowchart of the used methodology

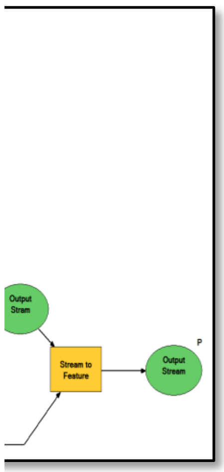

Figure 3: the flowchart for step one

Second raster elevation to watershed tool was four steps that must be achieved in order to obtain information with this tool as follows and as seen in Figure 4:

1- Input elevation raster parameter, from which the raster file is entered.

2- The parameter input raster or feature outlet data, from which the watershed point is entered after it has been defined in advance.

3- The outlet field parameter, from which the ID of the downstream point is determined.

4- The parameter output watershed polygon, from which the output is saved in the computer memory in vector format.

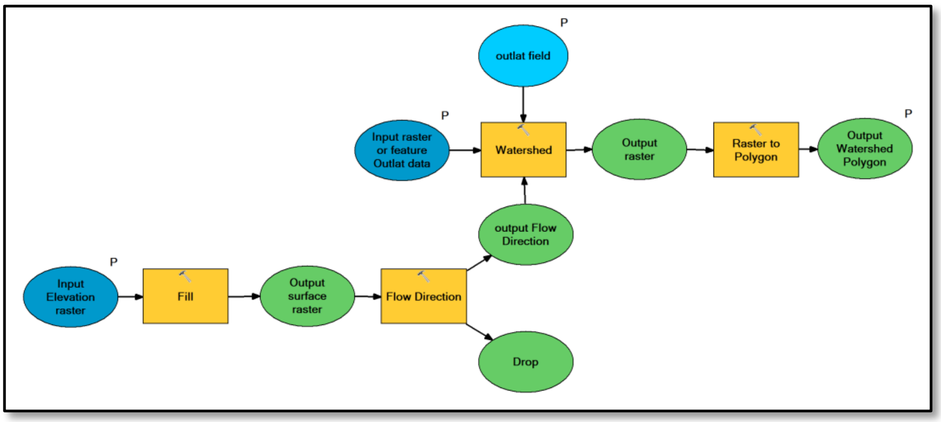

Figure 4: The flowchart for step two

The work of the developed tool (Raster elevation to water shed) has been improved by adding a source code from the ArcGIS Desktop library titled as (Snap pour point), which works on the automatic modification that detect the downstream outlet from the DEM to the nearest true outlet point when the user could not distinguish the correct outlet point from the used DEM as in shown in Figure 5.

```
import arcpy
from arcpy import env
from arcpy.sa import *
env.workspace = "C:/sapyexamples/data"
outSnapPour = SnapPourPoint("pourpoint", "flowaccumulation.img", 5,"VALUE")
outSnapPour.save("c:/sapyexamples/output/outsnpprpnt01")
```

Figure 5: The snap pour point Source code by Python Language

Results and Discussion

Two tools were developed to address the goal of the research, as each tool contains only four parameters, with the necessary explanation for each tool, in English, to ensure ease of use by the user, as shown in the Figure 6.

The outputs of the developed tools were compared with the original tools, where the results of the outputs were identical until the difference between them is reflected in the short number of transactions to be entered and according to the original tools to obtain the desired results from these tools, in addition to shortening the implementation time when comparing the developed tools with the original tools with achieving technical and spatial feasibility, and as shown in Table 1 and appendix.

Despite the lack of Arc GIS Desktop tools that work automatically in the derivation of hydrological features, but it has a suitable environment for the development of various tools and this feature can be exploited to address this lack. The developed tools can also be traded between specialists, provided that they have a copy of the Arc GIS Desktop V 10.1 software and the latest versions available in their computers.

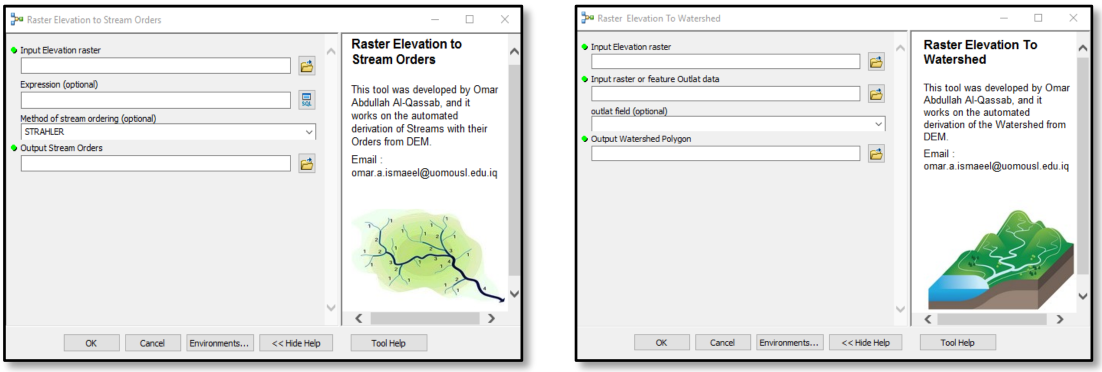

Figure 6: The interface windows of the developed tools

Table 1: Comparison between the developed and original tools based on number of steps and the time required for implementation

Derivation Type	**Original Tools**				**Developed Tools**			
	Tools Name	**Tools Number**	**Total parameters Number**	**derivation time**	**Tools Name**	**Tools Number**	**Total parameters Number**	**derivation time**
Stream Orders	Fill Flow Direction Flow Accumulation Build Raster Attribute Table Con Stream Order Stream to Feature	7	18	13 minutes	Raster Elevation to Stream Orders	1	4	58 seconds
Watershed	Fill Flow Direction Watershed Raster to polygon	4		7 minutes	Raster Elevation to Watershed	1	4	40 seconds

Conclusions

The process of developing tools must achieve two main issues in geographic information systems, including the first in the need to achieve technical feasibility, that is, achieving applied facilities and shortening them in the simplest form with more automation (automated work) and less possible intervention from the user during the work of the tool, and the second in the need to achieve spatial feasibility, in terms of the quality and objectivity of the results. GIS methods were utilized for delineating hydrographic basins as well as extracting a stream network from a DEM, with a focus on stream segmentations utilizing Strahler's theory and the Siref procedure in an automated workflow. The accurate and exact counting of the stream segments for every one of the orders was made possible by a Python algorithm, while the delineation of watersheds for every one of the stream orders has been made possible by a Java pour point tool based on Arc Objects. Starting from some initial values, the former tool was built to determine 16 appropriate threshold values for automatically modeling raster layer of drainage network. The iteration's intermediate findings allow comparing the extracted stream networks to topographic maps. Although there are similar tools that available within the ArcHydro extension produced by ESRI, this process of installing will slow down the analysis producers in general, unlike the tools that developed in this paper which is characterized by fast performance compared to the performance developing tool that installed in the ArcGIS Desktop.

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Appendix

1- Source code of Raster Elevation to Stream Orders Tool

```
# Raster Elevation to Stream Orders.py
# Created on: 2022-01-17 23:06:40.00000
# Usage: Raster Elevation to Stream Orders <Input_Elevation_raster>
<Expression> <Method_of_stream_ordering> <Output_Stream_Orders_>
# Description:
# ---------------------------------------------------------------------------
--
# Import arcpy module
import arcpy
# Script arguments
Input_Elevation_raster = arcpy.GetParameterAsText(0)
Expression = arcpy.GetParameterAsText(1)
Method_of_stream_ordering = arcpy.GetParameterAsText(2)
if Method_of_stream_ordering == '#' or not Method_of_stream_ordering:
    Method_of_stream_ordering = "STRAHLER" # provide a default value if
unspecified
Output_Stream_Orders_ = arcpy.GetParameterAsText(3)
# Local variables:
Output_surface_raster = ""
Output_drop_raster = ""
output_Flow_Direction = ""
output_Flow_Accumulation = ""
Output_Raster_table = output_Flow_Accumulation
Input_true_raster_or_constant_value = "1"
Input_false_raster_or_constant_value = ""
Output_raster = ""
Output_Stram_order = ""
# Process: Fill
arcpy.gp.Fill_sa(Input_Elevation_raster, Output_surface_raster, "")
# Process: Flow Direction
arcpy.gp.FlowDirection_sa(Output_surface_raster, output_Flow_Direction,
"NORMAL", Output_drop_raster, "D8")
# Process: Flow Accumulation
arcpy.gp.FlowAccumulation_sa(output_Flow_Direction,
output_Flow_Accumulation, "", "INTEGER", "D8")
# Process: Build Raster Attribute Table
```

```
arcpy.BuildRasterAttributeTable_management(output_Flow_Accumulation,
"NONE")
# Process: Con
arcpy.gp.Con_sa(Output_Raster_table, Input_true_raster_or_constant_value,
Output_raster, Input_false_raster_or_constant_value, Expression)
# Process: Stream Order
arcpy.gp.StreamOrder_sa(Output_raster, output_Flow_Direction,
Output_Stram_order, Method_of_stream_ordering)
# Process: Stream to Feature
arcpy.gp.StreamToFeature_sa(Output_Stram_order, output_Flow_Direction,
Output_Stream_Orders_, "SIMPLIFY")
```

2- Source code of Raster Elevation to Watershed Tool

```
# Raster  Elevation To Watershed.py
#(generated by ArcGIS/ModelBuilder)
# Usage: Raster  Elevation To Watershed <Input_Elevation_raster>
<Input_raster_or_feature_Outlat_data> <outlat_field>
<Output_Watershed_Polygon>
# Description:
# ------------------------------------------------------------------------
--
# Import arcpy module
import arcpy
# Script arguments
Input_Elevation_raster = arcpy.GetParameterAsText(0)
Input_raster_or_feature_Outlat_data = arcpy.GetParameterAsText(1)
outlat_field = arcpy.GetParameterAsText(2)
Output_Watershed_Polygon = arcpy.GetParameterAsText(3)
# Local variables:
Output_surface_raster = ""
Output_drop_raster = ""
output_Flow_Direction = ""
Output_raster = ""
# Process: Fill
arcpy.gp.Fill_sa(Input_Elevation_raster, Output_surface_raster, "")
# Process: Flow Direction
arcpy.gp.FlowDirection_sa(Output_surface_raster, output_Flow_Direction,
"NORMAL", Output_drop_raster, "D8")
# Process: Watershed
arcpy.gp.Watershed_sa(output_Flow_Direction,
Input_raster_or_feature_Outlat_data, Output_raster, outlat_field)
# Process: Raster to Polygon
arcpy.RasterToPolygon_conversion(Output_raster, Output_Watershed_Polygon,
"NO_SIMPLIFY", "", "SINGLE_OUTER_PART", "")
```