Determining Watershed Parameters Using Arc Hydro

Hema Gopalan, Tim Whiteaker and David Maidment

Abstract: The Water Availability Model (WAM) uses a GIS and hydrologic simulation models to evaluate existing water rights permits, permit approvals, and overall water management in Texas. The principal results from a WAM analysis are the reliability of existing water rights and monthly estimates of unappropriated water that would be available for diversion or storage. The current method of WAM GIS processing suffers from performance and data management issues. This paper discusses a new method of determining watershed parameters using the Arc Hydro toolset for the Brazos basin for both existing and new water rights.

Introduction: In response to the statewide drought of 1996, in 1997 the Texas legislature directed the Texas Commission on Environmental Quality (TCEQ) to develop a new water availability model (WAM) which not only allows the TCEQ to more accurately determine whether sufficient water is available for issuing new water right permits, but also allow planners to determine the amount of water available for each water right and the percentage of time it is available. The TCEQ chose the Water rights Analysis Package (WRAP) model developed by Ralph Wurbs at Texas A&M University as the new water availability model (Wurbs 2001). The WRAP is a hydrologic simulation model to evaluate, existing water right permits, permit approvals for new water rights, and overall water management in Texas under a priority based water allocation system. The principal results from a WAM analysis are the reliability of existing water rights and monthly estimates of unappropriated water that would be available for diversion or storage. These results are used to analyze the capability of a river basin to satisfy existing water use requirements and the amount of unappropriated streamflow remaining for potential additional water rights applicants. The Center for Research in Water Resources (CRWR), at The University of Texas at Austin developed watershed parameters to be used as inputs to the WRAP model. These parameters include the area draining to each control point, the flow length from each control point to the outlet of the basin, the control point connectivity, the average precipitation and the average curve number over the drainage area. Control points here collectively refer to the location of each diversion point, United States Geological Survey (USGS) stream gage and various other basin nodes like reservoirs, return flows, streamflows, evaporation etc. as specified by the contractor. Previously these parameters were developed in ArcView 3.2 and processing suffered from performance and data management issues. This research deals with determining the watershed parameters by a more structured and systematic approach using the Arc Hydro Data Model (Maidment 2002). The main objectives of this research are:

- To build a hydro data model for the WRAP project from the basic Arc Hydro model. This model is called WRAP Hydro.
- To devise a new method of defining the basin boundary to act as an analysis mask for processing grids and watersheds.
- To develop a new vector based method for determining watershed parameters using the WRAP Hydro model.
- To verify the validity of dividing the basin into subregions for parameter development.

- To explore the possibility of efficiently adding stream lines and control points after completing the process of developing the parameters so as to facilitate editing and updating of database.

Literarure Review: A set of tools were developed at the Center for Research in Water resources for determining the watershed parameters. These tools were scripts written in Avenue and were embedded in an ArcView 3.2 project called WRAP1117.apr. These tools prepare the data for extraction of watershed parameters and then perform the data extraction. To prepare the stream network, a tool in wrap1117 draws the stream network path taken across the DEM. A tool is included to snap the control points to the DEM derived network because accurate definition of watershed parameters requires that the control points be located exactly on top of a grid cell within this drainage path. The tools for raster data create the burn, fill, flow direction and flow accumulation grids from the DEM and the average curve number and average annual precipitation grids from the SCS curve number and annual precipitation grids. The toolset was first implemented on the Sulphur basin with two DEM resolutions, 90m and 30 m. It was found that 30 meter DEMs provided more accurate delineation of watersheds but the time to process the 30m data increased due to increased file size (Hudgens, 1999). For a more precise delineation, the surrounding streams of a basin, apart from the stream network within the basin, have to be taken into consideration. 30 m DEM-derived watersheds with a slope greater than 0.002 correlated to the US Geological Survey (USGS) reported watershed areas within 1%. At a slope less than 0.002, the percent difference from USGS values rose (Mason, 2000). For large watersheds, the data is too huge to be handled as one entity. This problem is dealt with by subdividing the basins into parts. The hydrologic cataloging unit provides a good boundary in terms of size to divide large basins. The independent processing of each subbasin or cataloging unit means that the resulting parameters do not include contributions from upstream or downstream areas that are required for WAM. The values obtained from each subbasin can be cascaded downstream to get the final parameters for the control points for the entire basin (Figurski, 2001). The Arc Hydro framework provides a simple, compact data structure for storing the most important geospatial data describing a water resources system. This framework can support basic water resources studies and models, and can serve as a point of departure for the most extensive data models, that include time series and other Arc Hydro components. The framework contains information organized in several levels (Maidment, 2002). This framework could be used to determine basin parameters in a structured manner and more efficiently than the WRAP1117 method.

Data and Methodology:

One of the main developments using the Arc Hydro framework is to connect it to hydrologic models like WRAP, HMS and RAS. The WRAP Hydro data model has been derived from the Arc Hydro model and is tailored specifically for the WRAP project. In Arc Hydro language, the streams are called HydroEdge, the points are called HydroJunctions and the delineated watersheds are called Watershed; and since the WRAP Hydro model has been derived from the Arc Hydro model, the respective feature classes are called WRAPEdge, WRAPJunction and WRAPWatershed. The WRAP Hydro data model is structured to suit the needs of the WRAP parameter processing. The feature classes and fields that are required for the WRAP process are retained, those that are not are removed and some others that do not exist in the Arc Hydro Framework and are required by the WRAP process are added. Figure 1 shows the WRAP Hydro model structure for the Guadalupe basin after the schema is applied to the repository.

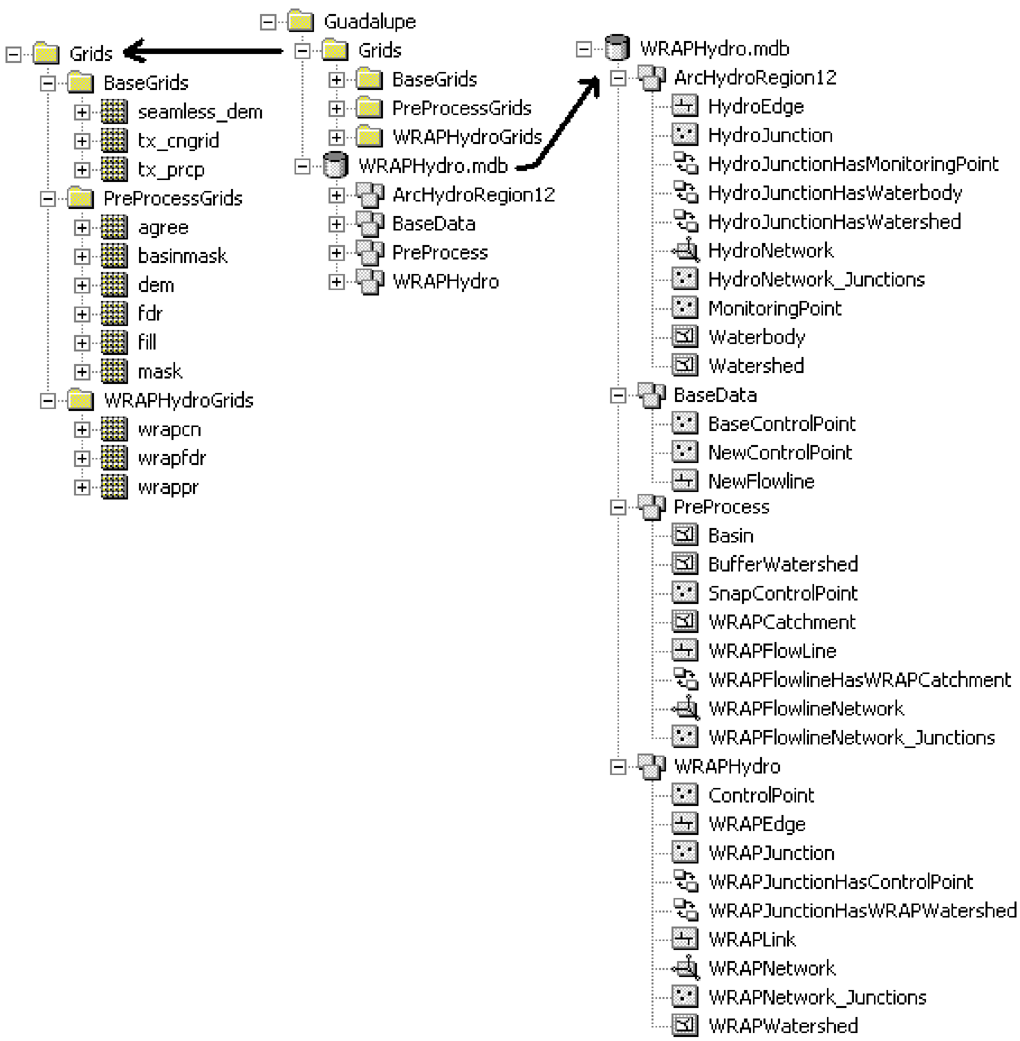


Figure 1: WRAP Hydro Data model structure

The Guadalupe basin folder has a folder ‘Grids’ and a personal Geodatabase ‘WRAP Hydro.mdb’. The grids folder contains all the grids needed for processing at different levels, ‘BaseGrids’, ‘PreProcessGrids’ and ‘WRAPHydroGrids’, The geodatabase has four feature datasets ‘ArcHydroRegion12’, ‘BaseData’, ‘PreProcess’ and ‘WRAPHydro’. Each of these datasets has feature classes that specify the mandatory fields that are contained within it.

Base data are all the data needed before any processing can start. The NHD network for Region 12 is obtained from USGS. This network, called the NHD in Geo, is created for the use of NHD in a geodatabase. It has a field FlowDir which contains attributes that define the direction of flow for each segment of the network. In ArcHydroRegion12, a Watershed is the area that contains all the HUC features in Region 12. The BaseControlPoints file contains all the water right points in a basin which includes stream gage locations, diversion points, return flow points or any other location on the stream where calculations of flow are done. Each record describes what type of water right point it is and what its WRAPCode is. The WRAPCode is a unique identifier given by the contractors according to their numbering conventions. New control points and stream edits are data that either is obtained after the final parameter processing or the features that had been accidentally left out.

The Digital Elevation Model is downloaded from the USGS site. To prepare the DEM for further processing, the merged DEM is first resampled to a cell size of 30 m. The cell values are changed to centimeter units and then converted to integers. This helps in reducing their storage space to a great extent. This data has a Geographic projection with datum NAD83 and spheroid GRS80. The curve number grid is obtained from the

Blacklands Research Center in Temple, Texas. This grid was prepared using the STATSGO soil coverage and the USGS Land Use Land Cover (LULC) coverage, by combining the soil and land values into curve numbers using the 1972 SCS Engineering Hydrology Handbook as a reference. Tx_prcp is a 250 m resolution annual precipitation grid for Texas. This was obtained from the Oregon State Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate grids.

The projection system chosen for this work is Texas State Mapping System (TSMS). It is a consistent map projection for Texas since it preserves the true earth surface area for polygons and this is important for this study when performing drainage area calculations. All the base data are projected to this projection system before any further analysis is done.

Two toolsets are used for the parameter processing – Arc Hydro toolset and WRAP Hydro toolset. Arc Hydro toolset has functionalities to Process the DEM, assign flow directions to the network and to read and write attributes to the tables. The WRAP Hydro toolset is used to delineate catchments, find certain watershed parameters and to add or remove junctions from networks. The detailed description of each tool can be found in the help file in these toolsets. After the base data is obtained the initial analysis area is defined and some preprocessing needs to be done before the final parameter development can be done. The preprocessing basically deals with defining the basin boundary to set the analysis extent for any further processing, since the Hydrologic Unit Codes (HUCs) obtained by the USGS that are contained within a basin do not rightly define it. A buffer of 10 Kilometers around the basin HUCs is considered for initial processing. The DEM is clipped to the buffered area and is processed to obtain the flow direction grid. The DEM is first reconditioned or in other words burned with the streams which raises the elevation of the cells that surround the stream. This is done to ensure that all the water that falls on the basin is captured by the stream and the stream follows the same path as in a topographic map. The next step is to fill all the sinks in the reconditioned DEM. A sink is defined as any cell that has a value less than all its surrounding eight cells. Its value is raised to the value of the lowest surrounding cell. Finally the flow direction grid is processed that assigns a value of flow direction to each cell in the grid according to the eight direction pour point method. It is important to consider the surrounding streams to ensure that all the stream segments within the basin have been taken into account before the processing starts. This is also important because the surrounding streams help in correct delineation of watersheds for the basin by delineating a catchment for every stream segment under consideration. The basin streams with the surrounding stream segments are called WRAPFlowline. This helps in avoiding the possibility of capturing area that does not belong to the basin under consideration. Figure 2 illustrates this.

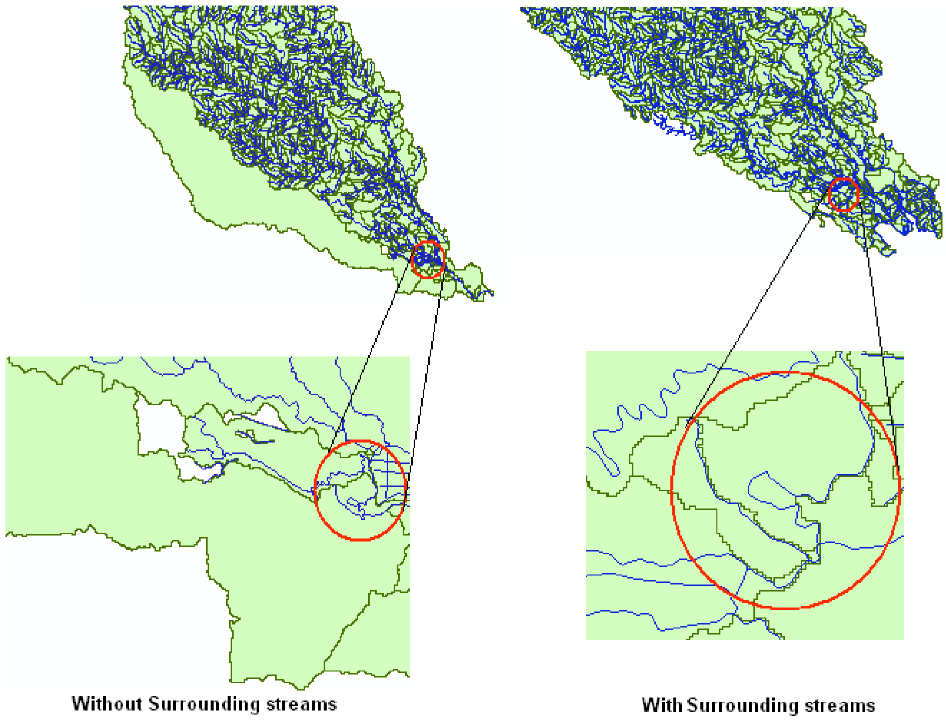


Figure 2: Catchment delineation with and without considering surrounding streams

Another important issue to be considered with delineation is the dangling edges in the network, which create holes during the delineation process (figure 3). To avoid this, these edges except the ones at the boundaries are deleted before delineating catchments.

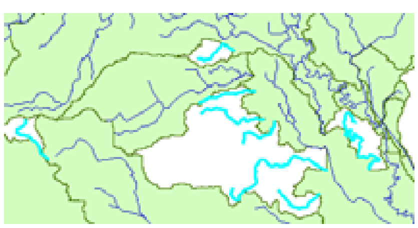


Figure 3: Holes created by dangling edges.

The catchments delineated by the stream segments that make up the Guadalupe basin are selected and dissolved using a common attribute to create the mask of the basin which defines the boundary of the basin for further processing. The SnapControlPoints are obtained by snapping the BaseControlPoint to the WRAPFlowline feature class.

After the base data are prepared and the preprocessing is done for the data it is ready for final parameter development. The main process of determining the watershed parameters is done in the WRAP Hydro feature dataset. The WRAPEdge feature class contains all the edges that lie within the basin mask. The BaseControlPoint features are exported to the ControlPoint feature class. The SnapControlPoint featureclass is exported to WRAPjunction featureclass and multiple points at the same location are deleted. Thus WRAPJunction contains just one junction at a location and the junctions are snapped to the network, SnapControlPoint has multiple points at a location that are snapped to the network and ControlPoints have multiple junctions that are in their original locations. A simple network is built using the WRAPEdge and WRAPJunctions to split the WRAPEdges at points where a WRAPJunction is located. HydroIDs which are unique identifiers for each feature are assigned to WRAPEdge and WRAPJunction using the Assign HydroID tool of the Attribute tool menu in the Arc Hydro toolset. The initial value of the HydroIDs are set using the HydroID table manager in the APUtilities tool in the Arc Hydro toolbar. The data is now ready for parameter development.

Next Downstream Junction: This parameter is populated in the NextDownID field in the WRAPJunction feature class. It shows the connectivity of the control point, indicating which point is next downstream of another. For any Junction, The Find Next Downstream Junction tool in the Arc Hydro toolset assigns the HydroID of the next downstream junction to the NextDownID of that junction. Any junction that does not have a junction downstream of it will be assigned a value -1. Thus, the outlet of the basin will always have a NextDownID value = -1

Length to outlet: This parameter is populated in the LengthDown field in the WRAPJunction feature class. The Calculate Length Downstream for Junctions tool in the Arc Hydro toolset is used to find the distance of each WRAPJunction from the outlet. It calculates the length in kilometers by adding up the lengths of all the WRAPEdges that are downstream of it.

Upstream Area Delineation: To find the total area that drains into each control point, incremental watersheds are delineated for each junction and their value is accumulated downstream. The delineation process is done using the WRAP Hydro toolset. The feature classes and grid names are specified in the Layer tab in the Settings form for the toolbar, fields are specified in the Fields tab, and the WRAPEdge is specified as the source layer for watershed delineation with JunctionID as source attribute in the Options tab. The IDs to Edges tool in the WRAP Hydro toolset is used to populate the JunctionID field in WRAPEdge with the HydroID of the next downstream junction. Thus, all the Edges between two junctions will have the same JunctionID (which is the HydroID of the downstream junction). Once all the JunctionIDs are populated, the Delineate Watersheds tool in the WRAP Hydro toolset is used to delineate watersheds for each junction. The watersheds are delineated using the flow direction grid to the Edges and the feature class is called WRAPWatershed. For each value of JunctionID of the edges, a watershed is created. Thus, a watershed is created for each Junction, since all the edges between two junctions have the same JunctionID. The DrainID field in the WRAPWatershed is populated with the JunctionID value of the Edges it is draining to. Thus in Figure 4, the HydroIDs of the WRAPJunction (red) are populated to the JunctionIDs of the WRAPEdge (Blue), which are in turn populated to the DrainIDs of the Watershed (Green).

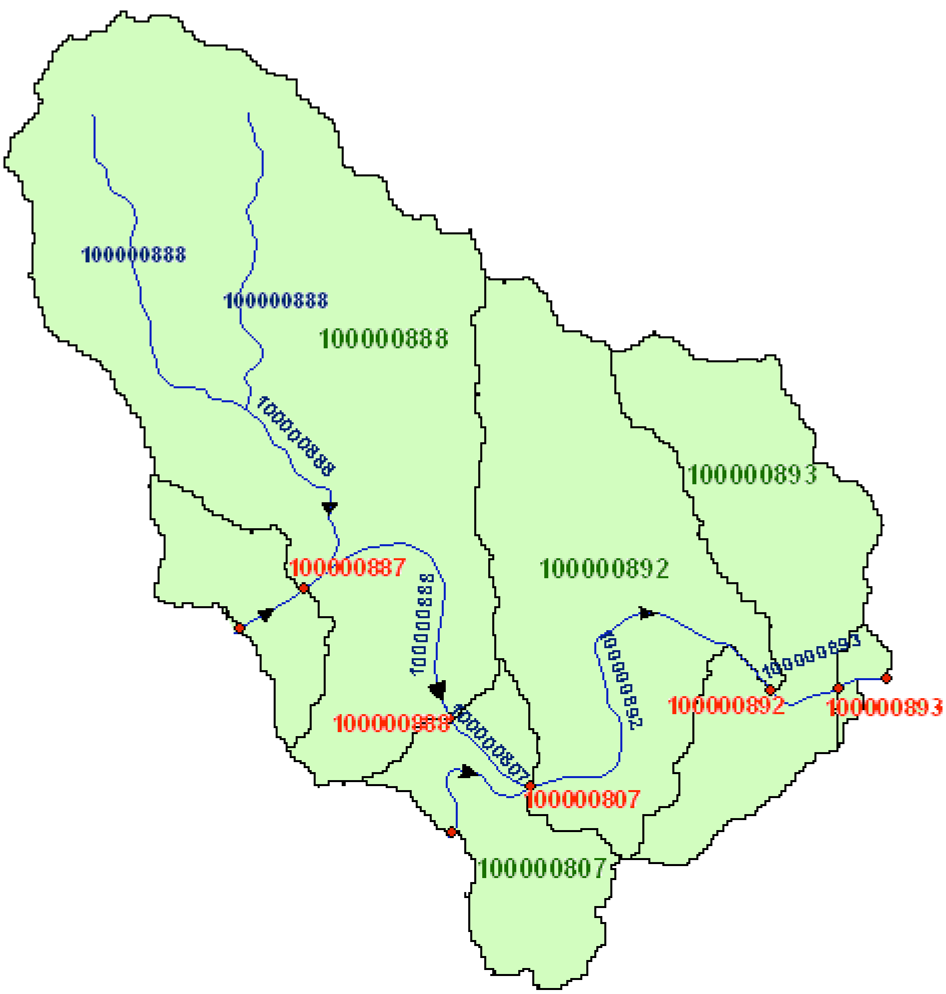


Figure 4: DrainID assignment in WRAPWatershed

Watershed Drain Area, Average Curve Number and Average precipitation: These values are populated in the DrainArea, AvgCN and AvgPR fields in the WRAPWatershed feature. The Average value of Curve Number and Annual Precipitation for each Watershed is the mean of all the cell values within that area. Once the incremental values for the drain area, curve number and annual precipitation have been determined for each feature in WRAPWatershed, these values are consolidated to add in the effects of all the area that is upstream of each junction. This is done using the 'Accumulate CN, Precip and Area' tool in the WRAP Hydro toolset. The drain area values are added downstream and are stored in the Drain_Area field in the WRAPJunction. The curve number and precipitation values are populated in the AvgCN and AvgPR fields in the WRAPJunction by taking a weighted average of the respective values over each watershed. This process is illustrated in Figures 5 and 6. Figure 5 shows three WRAPJunctions with HydroIDs 100000897, 100000898 and 100000994. For convenience they will be referred to as Junctions 897, 898 and 994 respectively. Similarly the WRAPWatersheds with respective DrainIDs will be referred to as watersheds 897,898 and 994. As it can be seen, junctions 994 and 897 are both upstream of junction 898. Thus, the effects of watersheds 994 and 897 will be seen in watershed 898. Figure 6 shows the attribute table for WRAPWatershed and WRAPJunction for the three junctions. The DrainArea value of junctions 994 and 897 will remain the same as that of their respective watersheds since the only area that drains into them is from their own watershed. But the DrainArea of junction 898 will be the accumulated area of all the three watersheds, i.e. 2.47 + 3.49 + 17.34 = 23.03. The average weighted curve number for the junction 898 is calculated by dividing the sum of the product of all the incremental curve number values with the respective incremental area by the total upstream area for that junction.

$$AvgCN_{898} = \frac{(71.64 \times 2.47) + (69.02 \times 17.34) + (65.01 \times 3.49)}{23.3} = 68.70$$

Similarly the average weighted precipitation for junction is calculated by:

$$AvgPR_{898} = \frac{(32.20 \times 2.47) + (32.53 \times 17.34) + (32.66 \times 3.49)}{23.3} = 32.51$$

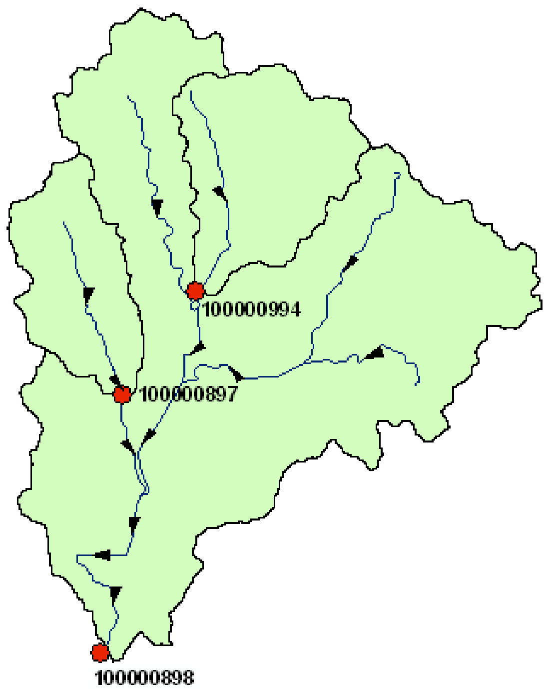
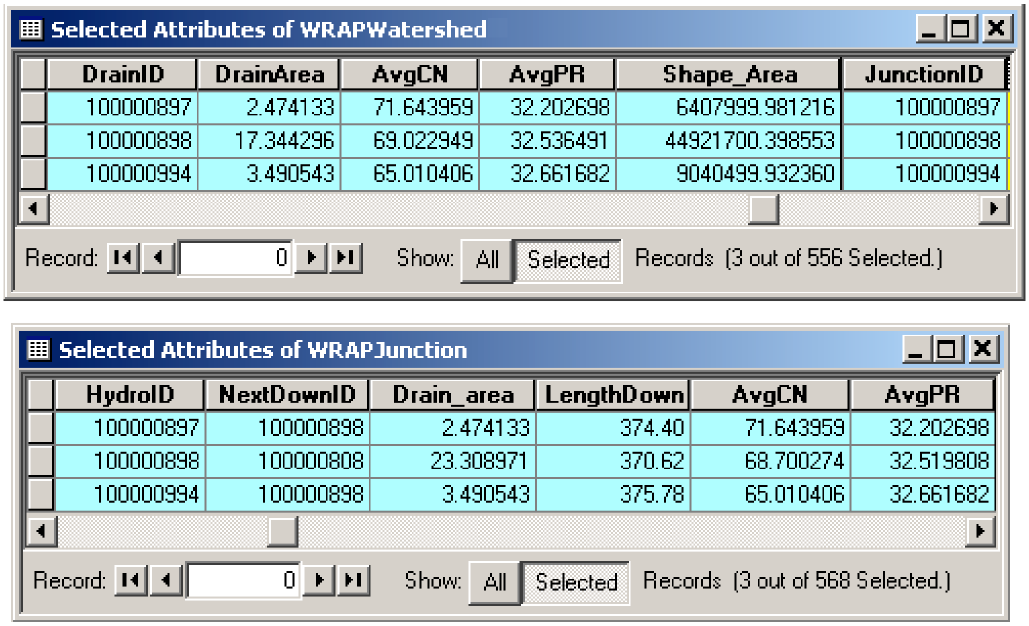


Figure 5: Illustration showing three WRAPJunctions whose values are accumulated downstream



Selected Attributes of WRAPWatershed

DrainID	DrainArea	AvgCN	AvgPR	Shape_Area	JunctionID
100000897	2.474133	71.643959	32.202698	6407999.981216	100000897
100000898	17.344296	69.022949	32.536491	44921700.398553	100000898
100000994	3.490543	65.010406	32.661682	9040499.932360	100000994

Record: 0 Show: All Selected Records (3 out of 556 Selected.)

Selected Attributes of WRAPJunction

HydroID	NextDownID	Drain_area	LengthDown	AvgCN	AvgPR
100000897	100000898	2.474133	374.40	71.643959	32.202698
100000898	100000808	23.308971	370.62	68.700274	32.519808
100000994	100000898	3.490543	375.78	65.010406	32.661682

Record: 0 Show: All Selected Records (3 out of 568 Selected.)

Figure 6: Attribute tables showing incremental values in WRAPWatershed and Accumulated values in WRAPJunction

The last step in parameter development is to copy the attributes from WRAPJunction to all the points including the coincident ones in the Control Points feature class. The 'CP tools' in the WRAP Hydro toolset is used. The Settings form is used to specify layers, fields, and processing options to be used by various functions in the WRAP Hydro toolset. The 'IDs to Control Points' tool populates the HydroID of the WRAPJunction to the JunctionID of the ControlPoint point based on spatial location. Thus JunctionIDs are calculated only for coincident features. Since in the ControlPoint feature class, the features have not been snapped to the network to retain their location as given by the TCEQ, the SnapControlPoint feature class in the Preprocess feature dataset is used for intermediate calculations.

Regionalization: When working with huge basins, the computer processor might not be able to handle the large datasets, especially the raster processing part. This is dealt with by dividing the basin into sub regions and processing grids individually for each region. The results from each sub basin are merged on the vector side for determining parameters. The regional WRAP Hydro structure is illustrated in Figure 7.

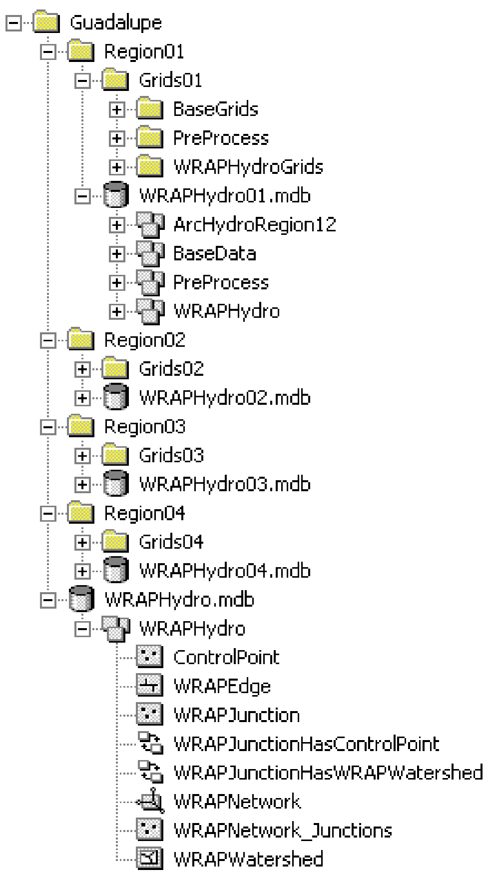
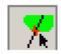
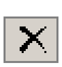


Figure 7: Regional WRAP Hydro structure.

When dealing with sub basins, four in case of Guadalupe, the main Guadalupe folder has four folders (one each for a region). Each region has a 'grids' folder and a 'WRAP Hydro' geodatabase suffixed by the region number. Individually they have the same structure as the WRAP Hydro model in Figure 1. The Guadalupe folder has a Geodatabase WRAPHydro.mdb that has one Feature dataset, WRAPHydro. This geodatabase contains the merged product from each regional processing.

The methodology of dealing with sub basins is similar to the method described earlier in this section. Instead of working with the whole basin, parameters and grids are processed individually for each sub region. The grids are clipped to this mask. A network is built using the WRAPEdges and WRAPJunctions and an outlet point is placed in each of the four areas. Watersheds are delineated for each JunctionID value of WRAPEdge. The four WRAPEdges, WRAPJunctions and WRAPWatersheds are then merged and the parameters are processed. When assigning HydroIDs to the sub basin WRAPJunctions and WRAPEdges, it is essential to specify the region to which they belong to make it easier to identify them when the four areas are merged. This is particularly useful when new edits (Junctions or Edges) are added after the base processing is done. The new edits will be assigned HydroIDs according to the subbasin they are added in which makes it easy to identify them after they are merged in the final step.

Adding new streams and junctions: After the parameters are determined for a basin either as one unit or by splitting into parts, there are chances that some Edges or Junctions or both may be left out of processing. Usually new junctions are added when a new water right permit is granted, a new stream gage location is added to the existing ones, or for any other reason. There also might be points that would have been overlooked. Some stream segments may be omitted while digitizing. It wouldn't matter to omit these streams since the DEM would take care of the watershed delineation, but if there are control points on these stream segments, the watersheds need to be delineated for each of these points. This is when it becomes necessary to add a stream segment to the network.

The buttons ‘Process New HydroJunction’  and ‘Batch Process HydroJunctions’  in the WRAP Hydro toolset are used to incorporate new junction edits into the network. These tools are used when the new junctions have to be added on an already existing stream network. If there is only one new junction, the Process New HydroJunction is used. A watershed is delineated for that junction and the other parameters, NextDownID, Drain_area, average curve number and precipitation values are populated automatically in the respective fields. When several new junctions are added, rather than processing each one individually a batch processing is done on them. This creates a new watersheds file and updates all the other parameters as well. However, both these tools do not compute the length downstream and the LengthDown field has to be populated using the ‘Find Length Downsream for Junction’ tool in Arc Hydro toolset. Sometimes, some existing water right permits are cancelled and no calculation needs to be done on that location. Also, a junction may be wrongly placed on the network or may have shifted in location due to a given snapping environment or any other reason. In these cases a junction has to be removed from the network using the ‘Remove HydroJunction tool’  in the WRAP Hydro toolset. When a junction is removed from the network, the NextDownID of the upstream junction, the JunctionID of the upstream edge and the DrainID of the Watershed it delineated are automatically updated.

It becomes necessary to add stream segments when new control points are located on them. Every time a new stream edit is added, the DEM has to be processed again. This is very time consuming, especially if the basin is not processed in parts since the whole procedure of processing the DEM, delineating catchments and populating parameters has to be repeated. To deal with this problem, the first step is to identify the delineated watershed(s) that the stream edits lie within. The selected watershed that contains the new stream and control point is exported to a new feature class and converted to a raster mask. The new edits are imported into the WRAPJunction and WRAPEdge feature classes. This assigns the new features their HydroIDs in sequence with the existing HydroID values. All the WRAPEdges and WRAPJunctions that lie within the new exported watershed are selected (which includes the edits), and exported to new feature classes. The DEM is clipped to the mask and is processed to get the flow direction grid for that small watershed. If the new stream segment(s) pass through more than one existing watershed, all the watersheds it passes through have to be selected. Figure 8 shows the selected watershed for the new stream edit and the watershed delineated for the junction on the new stream segment.

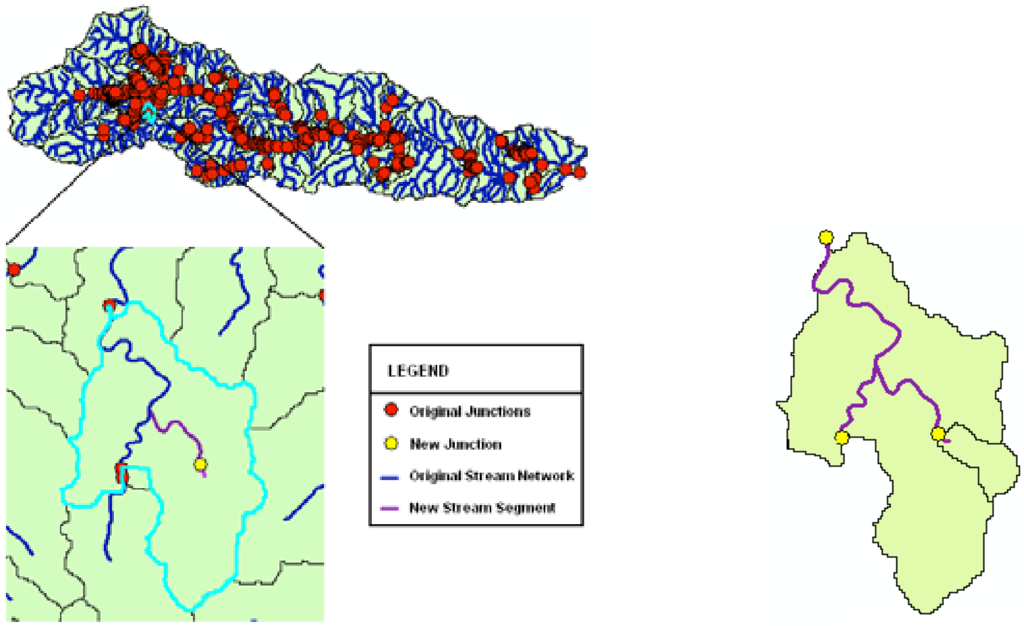


Figure 8: Delineating Watershed for new stream segment

Results:

Stream Gage Area Comparison: The results obtained for total upstream area for stream gages from three different methods are compared to the USGS reported value for these stream gages. These stream gages are evenly distributed across the Guadalupe basin. Hence they are used as representative points for comparison. The three methods are: WRAP Hydro method for parameter development for the whole basin, WRAP Hydro-Regional method of working with a basin in parts and the WRAP1117 method of determining parameters in ArcView. For convenience they are referred to as methods (1), (2) and (3) respectively. Table 1 and Table 2 show the values calculated for stream gages by the three methods and the percent difference in these values with respect to the USGS area.

ID	%Diff	%Diff_Region	%Diff_1117
1	0.2966	0.2966	0.1454
2	0.1709	0.1709	0.0228
3	0.6320	0.6320	0.2611
4	0.0373	0.0373	-0.0679
5	0.7171	0.7171	0.3538
6			
8	0.0556	0.0556	-0.0873
9	-0.0118	-0.0118	-0.1044
10	-0.0513	-0.0513	-0.0967
11	-0.2566	-0.2566	-0.5275
12			
13	0.2303	0.2303	-0.0091
14	0.0591	0.0591	-0.0203
15	0.2099	0.2099	0.0408

ID	Area_USGS	Drain_area	Drain_area_region	Area_1117
1	839.000	836.476	836.512	837.780
2	1315.000	1313.231	1312.753	1314.700
3	1436.000	1426.489	1426.924	1432.250
4	1518.000	1516.817	1517.433	1519.030
5	130.000	129.420	129.068	129.540
6		2101.816	2100.773	2103.070
8	355.000	355.264	354.803	355.310
9	412.000	412.336	412.049	412.430
10	838.000	838.745	838.430	838.810
11	309.000	310.077	309.793	310.630
12		459.925	459.715	459.790
13	549.000	548.820	547.735	549.050
14	4934.000	4932.783	4931.082	4935.000
15	5198.000	5188.828	5187.091	5195.880
38		5941.848	5943.252	10122.300

Drain_area is obtained from method 1, Drain_area_region from method 2 and Area_1117 from method 3. The areas are in square miles. The USGS areas were not available for three of the stream gages: 6, 12 and 38. The values for stream gages 1 through 15 in each case match very closely to the USGS area.

Length Downstream Comparison: The length downstream values in miles are compared in Table 3 for the three methods. Results from methods 1 and 2 are the same, but differ considerably from the results from method 3. This difference is attributed to the fact that in WRAP1117, DEM derived stream networks were used for determining parameters which can either increase or reduce the actual length of the stream network. Thus, the LengthDown values from methods 1 and 2 are more accurate as the streams are not altered during processing.

WRAPCode	LengthDown	LengthDown_Region	LengthDown1117	Percent Difference
1	387.28	387.28	402.01	-3.80
2	324.21	324.21	330.75	-2.02
3	299.39	299.39	302.41	-1.01
4	277.77	277.77	278.36	-0.21
5	277.7	277.7	278.06	-0.13
6	178.52	178.52	176.84	0.94
7	279.54	279.54	277.26	0.82
8	262.63	262.63	257.96	1.78
9	212.11	212.11	208.07	1.90
10	210.19	210.19	206.29	1.86
11	155.94	155.94	153.74	1.41
12	125.97	125.97	125.21	0.60
13	101.91	101.91	100.48	1.40
14	52.03	52.03	50.08	3.75
			Average =	0.52

Table 3: Length Downstream Comparison

The fifth column shows the percent difference in Method 1 and method 3 (methods 1 and 2 have the same result). Thus on an average, the NHD network is 0.52 % longer than DEM derived stream network as calculated by the values for the stream gages in Guadalupe basin.

Average Curve Number and Average Precipitation Comparison: The average curve number and precipitation values for methods 1 and 2 are compared in Table 4. These values were not calculated by method 3 for the Guadalupe basin. The results show an exact match in values for both these parameters.

ID	AvgCN	AvgCN_Region	AvgPR	AvgPR_Region
1	59.99	59.98	29.06	29.06
2	61.81	61.82	30.42	30.42
3	62.92	62.91	30.70	30.70
4	63.06	63.06	30.92	30.92
5	62.05	62.06	34.08	34.08
6	64.75	64.75	31.80	31.80
8	70.42	70.41	33.63	33.63
9	69.26	69.26	33.71	33.71
10	68.78	68.78	34.07	34.07
11	68.69	68.69	34.13	34.13
12	62.90	62.90	36.08	36.08
13	64.92	64.94	33.08	33.09
14	66.40	66.40	33.27	33.27
15	66.60	66.60	33.39	33.39

Table 4: Comparison of Average Curve Number and Average Precipitation Values

Conclusions:

WRAP Hydro is a much more efficient and accurate method of determining watershed parameters for water rights than previously used techniques. The WRAP Hydro model provides a very organized and structured platform to work on. By dividing the work into three stages: base data acquisition, preprocessing and actual parameter development on both raster and vector data, the data processing becomes more systematic and easy to manage. Migrating from a raster environment in ArcView 3.2 to a more vector environment in ArcGIS considerably reduces the complexity and the time taken for obtaining watershed parameters. The ability to create a network and assign flow direction saves a lot of time and labor. When dividing the basins into parts and working with each part individually, the accuracy of the watershed parameter values is not compromised in WRAP Hydro. Assigning unique identifiers, HydroIDs, for each feature helps in better identification of the features belonging to each subregion after they are merged to get the regional form for parameter development. The WRAP Hydro tools add and remove junctions and simultaneously update the parameters in the affected features automatically. This not only speeds up the process of incorporating edits but also reduces manual errors that could occur in updating parameter values.