ABSTRACT
An extension of the ArcHydro data model and tools developed at the Center for Research in Water Resources (CRWR) of the University of Texas has been successfully applied to the Rio Grande/Bravo basin geodatabase, a binational dataset created at the CRWR, automating a process called “raster – network regionalization.” This process allows determination of reach catchments for each individual river segment and delineation of watersheds draining to points on a river network by first splitting the network at those points, labeling all the lines upstream of a given outlet point with a unique number called a HydroID of that outlet point, and then invoking the watershed delineation function in ArcHydro to delineate the area draining to this set of lines. Once done for individual raster regions, the results can be integrated using the HydroID assignment process in ArcHydro so that accumulated drainage areas are automatically determined over a whole river basin. Because the geodatabase created for the Rio Grande/Bravo basin is binational, drainage areas and properties can be determined for the United States side only, for the Mexican side only, or for both sides of the river together.

INTRODUCTION
The Rio Grande/Bravo basin includes three states on the U.S. side (Colorado, New Mexico, and Texas), and five states on the Mexican side (Chihuahua, Coahuila, Durango, Nuevo Leon, and Tamaulipas). From the basin area, 225,380 Km$^2$ lies on the Mexican side and 242,994 Km$^2$ on the U.S. side, without considering closed basins (Patino et al, 2004).

The Center for Research in Water Resources (CRWR) of the University of Texas at Austin, the Texas Commission on Environmental Quality (TCEQ), and the National Water Commission (CNA) of Mexico has developed a binational dataset to build a hydrologic data model of the Rio Grande/Bravo basin. This dataset consists of a georeferenced data set based on the ArcHydro schema that contains temporal and spatial information. Several feature datasets were created that include feature classes related to each type of information.

When working with large basins like the Rio Grande/Bravo, is difficult, if not impossible, to process the entire raster data set as a whole. This is dealt with by dividing the basin into sub-regions and processing the sub-regional grids individually. The values obtained for each sub-basin can be cascaded downstream to get the final parameters for the entire basin. For this reason, the Rio Grande/Bravo basin was divided into 9 hydrological subregions on the U.S. side, according to the USGS classification, and 7 hydrological subregions on the Mexican side for its analysis (Figure 1), each subregion having its own unique identification numbers (HydroIDs) set up in such a way that when all 16 sub-regional geodatabases are merged the HydroIDs are also unique at the regional level. This way, overall drainage areas can be calculated by the ArcHydro accumulation function executed over the river network and related incremental drainage areas found from the sub-region raster analysis.
Applying Regional HydroID’s

A unique ten-digit identification number called the Regional HydroID was assigned to every feature class according to the following classification:

- The first digit (from left to right) indicates the hydrological region. Region 13 on the U.S. side was identified with the number 1, and number 2 identified region 24 on the Mexican side. The second 2 digits describe the Hydrologic SubRegion. The basin is divided into 9 subregions on the U.S. side and 7 subregions on the Mexican side. The next two digits correspond to the feature class. The value 01 was assigned for the ControlPoint feature class, while the value 02 was assigned for edges (River network). The waterbody feature class was identified as 03, Watershed as 04; and so on. The last five digits describe the feature number, with a maximum of 99,999 values. The Regional HydroID for the Rio Conchos basin is shown in Table 2 as an example.
Table 1  Regional HydroID for the Rio Conchos Basin with original Mexican Code preserved.

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEX_CODE</th>
<th>HydroID</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. CONCHOS - CUINAGA</td>
<td>24J</td>
<td>2020400001</td>
</tr>
<tr>
<td>R. CONCHOS - P. EL GRANERO</td>
<td>24K</td>
<td>2020400002</td>
</tr>
<tr>
<td>R. SAN PEDRO</td>
<td>24N</td>
<td>2020400003</td>
</tr>
<tr>
<td>R. CONCHOS - P. DE LA COLINA</td>
<td>24L</td>
<td>2020400004</td>
</tr>
<tr>
<td>R. FLORIDO</td>
<td>24M</td>
<td>2020400005</td>
</tr>
</tbody>
</table>

WRAPHYDRO DATA MODEL SCHEMA

A particular application of the ArchHydro data schema called WRAPHydro was applied to each of the Rio Grande/Bravo hydrological subregions in order to create the necessary fields required by the Water Right Analysis Package (WRAP) model (Wurbs, 2001). The WRAPHydro data model was derived from the ArchHydro model and is tailored specifically for the WRAP project developed jointly with the TCEQ (Gopalan, 2002). It is shown in figure 2. The WRAP is a hydrological simulation model for evaluating existing water right permits, permit approvals for new water rights, and overall water management in Texas under a priority based water allocation system (Wurbs, 2001).

Fig. 2. WRAPHydro Data Model.
All of the fields created by the WRAP Hydro schema were populated using the WRAP Hydro tools developed at the CRWR (Whiteaker, 2004). These tools consist of a set of public domain utilities developed on top of the ArcHydro data model. The tools are accessed through the WRAP Hydro toolbar, where they are grouped by functions into two menus and five buttons (Figure 3). The purpose of this toolkit is to process GIS data in order to calculate parameters used by WRAP and tabulated for each ControlPoint including: average curve number, average annual precipitation, total upstream drainage area, and next downstream ControlPoint.

**Fig. 3. WRAP Hydro Toolbar.**

**APPLYING THE WRAP HYDRO TOOLS**

For each hydrological subregion, the HUCs or SubCuencas that make up the subregion were selected, including a 10 Km buffer around the HUCs called the BufferWatershed feature class. All the streams that lie within each subregion plus buffer were selected and exported to create the WRAP-Flowline feature class. After this step, a digital elevation model (DEM) of the buffered area was clipped and processed using the ArcHydro Terrain Analysis tool. The catchments for each stream segment (WRAPCatchments) of the WRAP-Flowline class were created with the WRAP Hydro Delineate Watershed tool. The DrainID of the delineated catchments was populated by the HydroIDs of the WRAP-Flowline segment draining to it. In order to create a geometric river network (the HydroNetwork), the hydrography information had to be checked. Every stream must be connected and the flow direction assigned correctly. The HydroNetwork is an essential part of this data model, created from edges (WRAPFlowlines) and the control points. The topological connections of the edges and control points in a geometric network enables tracing of water movement upstream and downstream through streams, rivers, and water bodies. Relationships built from the control points connect drainage areas and point features such as diversion points to the HydroNetwork. This HydroNetwork allows calculation of the distance between any two points on a flow path. A new feature class called WRAP Edge was created using the HydroNetwork selecting all streams lying in the hydrological subregion. In order to find the total drainage area for each control point, it is necessary to determine the incremental watersheds that contribute to each junction, then their value is accumulated moving downstream. Watershed drainage
area, average curve number and average precipitation were calculated for each delineated watershed using the WRAPHydro tools. The Once the incremental values for the drainage area, curve number and precipitation were determined for each watershed, these values were consolidated to add in the effects of all the area contributing to each junction.

Figure 4 shows the result of comparing the SubCuencas of the Rio Conchos basin defined by the Instituto Nacional de Estadistica, Geografia e Informatica of Mexico (INEGI)--represented by a continuous line--and the watershed defined by the WRAPHydro Tools--represented by polygons. The connectivity among control points is shown in figure 5. The SubCuencas were defined using a 1:250K scale topographic map, while the watersheds were calculated from a 1:100K scale WRAPEdge (from a digitized map) and a DEM grid size of 30 m. The points represent the related water rights, gage stations, and return flow control points.

![Fig. 4. Rio Conchos Basin Delineation](image1)

![Fig. 5. Rio Conchos Basin Connectivity](image2)

**RASTER-NETWORK REGIONALIZATION PROCESS**

The research presented in this project introduces a Raster-Network Regionalization Technique, which allows a large region to be divided into hydrological distinct subregions where raster analyses may be performed in a feasible manner. A summation of raster values over watersheds can be easily determined using the watersheds as distinct zones which define the area of analysis for the zonal statistics tool in ArcGIS. This tool calculates statistics such as mean, sum, max, and min for each zone by reading the values of cells within each zone and performing the necessary statistical operations. Thus, with this approach, accumulated grids whose cell values are influenced by all upstream cells are no longer needed. The only cells of a watershed that an analyst is interested in are the cells that lie directly over that watershed (Whiteaker, 2004).

Once attribute values have been determined for watersheds, these values can be transferred to outlet junctions, and then consolidated throughout the stream network in the vector domain. The
watersheds become the basic processing unit with basin-wide coverage, while the raster coverage can be reduced to each individual watershed’s extent. Thus, watersheds effectively replace grid cells as the “units” of analysis.

This allows a basin or region to be divided into hydrologically distinct subregions, in which the necessary raster analyses takes place. The smaller size of the subregions permits faster raster processing, while results from raster analysis are stored on vector watersheds to be accumulated at the basin level. The Consolidation and Accumulation options from the WRAPHydro tools are then used to accumulate watershed parameters across the entire basin.

With the Raster-Network Regionalization technique, the weight of processing is changed from the raster side to the vector side, resulting in several benefits due to reduced processing time, since much of the processing occurs in the vector domain rather that in the raster domain. Data storage requirements are reduced, since accumulation grids no longer need to be created. Also, the remaining grids can be split into hydrological distinct regions defined by one or more watersheds. This allows for faster processing on the raster side, more modular data storage, and less raster reprocessing effort if data in a given watershed changes. Even the largest basin can now be processed with high-resolution raster data too.

The technique has been successfully applied to the binational Rio Grande/Bravo basin, which has a contributing area of over 468,000 square kilometers and is divided in 16 hydrological subregions as it is shown in figure 1(9 on the U.S. side and 7 on the Mexican side). The results from the raster analysis of each subregion are merged on the vector side for determining the total drainage area flowing toward a specific control point, as well as its corresponding average precipitation, average curve number, and length downstream parameters.

Figure 6 shows the control points and main rivers in the portion of the Rio Grande/Bravo basin from El Paso/Cd. Juarez through the Gulf of Mexico. The connectivity among the river system, junctions and watersheds is shown in figure 7.

**Fig. 6. Control Points and Main Rivers in the Rio Grande/Bravo basin**
Fig. 7. Connectivity in the Rio Grande/Bravo basin

Fig. 8. Schematic Network of the Rio Grande/Bravo basin
A schematic network diagram for the whole basin is shown in figure 8. This schematic network is a simplification of the HydroNetwork that consists of separate point and line feature classes called Schematic-Node and Schematic-Link, respectively. The schematic network is an abstract representation of the elements to which hydrologic or water management models can be applied, and it provides a simplified view of the connectivity of the river network and the control points. This kind of network is useful as a visual check to make sure that the hydrologic elements needed for a model are correctly linked in the landscape (Maidment, 2002).

CONCLUSIONS

One of the most important contributions of this research is the application of a Raster-Network Regionalization technique, which utilizes raster-based analysis at the subregional scale and network-based attribute accumulation at the regional scale in order to process large regions in an efficient manner. For large watersheds such as the Rio Grande/Bravo basin, the raster data is too large to be handled as one entity; this problem is dealt with by subdividing the basins into parts. The results from each sub-basin are merged on the vector side for determining parameters. This methodology helped to verify the validity of dividing a basin for processing without compromising on the accuracy of the parameter values determined. This technique could also be applied at a local level when high resolution data, such as LIDAR data, area available. These data are so dense they typically preclude raster analysis over a relatively small area.

A powerful conclusion from this research is that regional HydroID assignment is critical to the success of regionalization. The HydroID enables the connection between features in the landscape, including the connection of watersheds to outlet junctions, as well as the connection of junctions with next downstream junction. Also, it allows the integration of subregions into regions, through the update of the NextDownID in the most downstream junction in each region.

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REFERENCES


