A GIS DATA MODEL FOR SPATIAL WATER BUDGETS

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INTRODUCTION

Basin water routing is guided by its interaction with the atmosphere, surface water, groundwater, soil, vegetation and cultural features. A spatial water budget (SWB) of these components can be prepared using modeled or measured flows. Water-use management actions are often evaluated by comparison of water budget components with and without a project of interest. That fraction of water that is returned to the atmosphere by evaporation and transpiration (ET) is consumptive use (CU).

CU is a spatially distributed ET surface function (Cooper and others, 1998) dependent upon the availability of water resulting from precipitation as well as irrigation operations, cropping, land use, and other water management operations. Regional estimates of CU are often derived as the product of a lumped-parameter unit CU factor (such as crop coefficients) and classified land unit areas. Two examples of that approach are the web based BOR Agricultural Water Resources Decision Support system (BOR, 2003) and the 1940 Pecos River Joint Investigation (Natural Resource Planning Board, 1940) example presented on Figure 1. Such estimates can be updated for different time periods using remotely sensed Fractional Green Vegetated Areas (FGVA) or land cover maps.

Another approach involves applying meteorological surface energy balance techniques such as SEBAL or MATRIX from remote sensor imagery and local climatic data (Moran and others, 1989; Kramber, 2002; Bastiaanssen and others, 2005; and Allen and others, 2005). The result is a continuous surface of instantaneous or correlated seasonal ET. Accounting units can be assembled with some flexibility. CU can then be summarized per unit or viewed at full resolution. Where instantaneous estimates are unsatisfactory, unit CU values can be applied. The advantage of examining the distributed pixel-sized surface of data lies in discriminating high water-use rates from low water-use rates within a land use classification. Management alternatives can then be evaluated in the context of those water-use rates. Spatially distributed quantities can also be ideal for the parameterization of hydrologic models.

ACCOUNTING UNITS

Four major categories where CU occurs are broken into seven general accounting units each with evaporative loss, soil moisture and groundwater components.

FIGURE 2. EXAMPLE CU ACCOUNTING UNITS

Lateral Service Area (LSA) (Area under ditch)

1. *Agricultural* – Area of managed water application.
2. *Conveyance* – Area of open water and vegetation cover within a defined distance to a conveyance structure.
3. *Other LSA* – Sources of water include: wells, municipal supply, shallow water table and tailwater including a mix of managed and unmanaged sources.

Riparian Zones

4. *Riparian* –The riparian zone consumes water from river and drainage conveyance losses.
5. *Open Water* – Water surface evaporation.

Lands Outside LSA

6. Lands outside LSA and riparian areas that are not accessible to ditches but consume irrigation return flow and induced recharge. Sources of water include: wells, municipal supply, shallow water table, and a mix of managed and unmanaged uses.

Storage Facilities (not shown)

7. *Open Water* – Water surface evaporation.

Further accounting distinction is by overlay of designated administrative areas, land ownership, historical land cover and hydrologic boundaries. CU water quantities can be refined for project water accounting or water rights by spatially defining soil moisture, groundwater and effective precipitation to determine irrigation requirements.

DATA MODEL

A data model can serve as a template for integrating the layered spatial accounting units with remote sensing derived calculations and meteorological data required to compute a SWB. The ESRI geodatabase is suitable for the model because Arc-GIS is easily extendable, it interacts well with other software and it is scalable. Geo-database data models have been applied to multiple systems including atmospheric and hydrologic studies (see: http://support.esri.com/index.cfm?fa=downloads.dataModels.gateway).

A generalized Arc-GIS based data model was developed to meet five goals:

1. Flexibility to combine and create accounting units from administrative boundaries, land parcels, service areas, land coverage, ditches, streams and drainage networks.
2. Compatibility with Arc Hydro data model (Maidment, 2002) and the National Hydrography Dataset in Geodatabase. (USGS, 2004)
3. Ability to provide for temporal representative periods.
4. Interaction with hydrologic model data including spatial parameters such as grids and reach segments.
5. Compatibility with a toolset for accounting unit creation, basic image processing and other geographic information system analysis techniques.

There are five general model components: Hydrologic model (HydroModel) areas including gridded representations of streams, ditches and drain segments, return flow and ET areas; Raster surfaces (HydroBudgetRaster) including remotely sensed vegetation cover and soil moisture, surface energy balance components and distributed CU; Accounting unit boundaries (HydroBudgetUnits); Meteorological (HydroMet) station locations and parameters, NEXRAD HRAP cells and PRISM cells; and Time series data following the Arc-Hydro schema for model results such as stream leakage, and climate components.

All five can be multi-temporal with a facility to define representative periods. Model features are described on Figure 3 and in diagrams using Microsoft Visio and Universal Markup Language (UML) on Figure 4.

PROCESS STEPS AND TOOLS

SWB preparation usually requires multiple software packages with capabilities in hydrologic modeling, GIS and image processing software. The general workflow includes: defining hypsometric river plains and basins, selecting stream reach segments of interest, using land cover data to define riparian zones and defining ditch service areas, conveyance corridors and storage facilities from stream network data. Administrative units of interest are then identified and the tract level data or land cover data representing the lowest level accounting unit is added. Accounting units are then created by GIS intersection and identity operations. The result is a spatially partitioned dataset with a unique identifier.

After examination of meteorological data, a surface energy balance and ETrF (fraction of ET) for a period of interest can then be calculated or CU can be calculated spatially by land cover type with lumped parameter or with energy balance techniques. Zonal statistics for tracking CU within each accounting unit can then be calculated and refined by spatial rainfall data, modeled hydrologic flows and observed gaging data. Cross tabulation of accounting units can then be summarized in table and chart form. Reach by reach parameters for groundwater or surface water models can also be generated.

CONCLUSION

A flexible geo-database template has been described. We have successfully applied these techniques and tools for the development of spatial water budgets in New Mexico. The geo-database template facilitates the assembly of accounting units and its associated data processing. The Template will be made available at: www.balleau.com.

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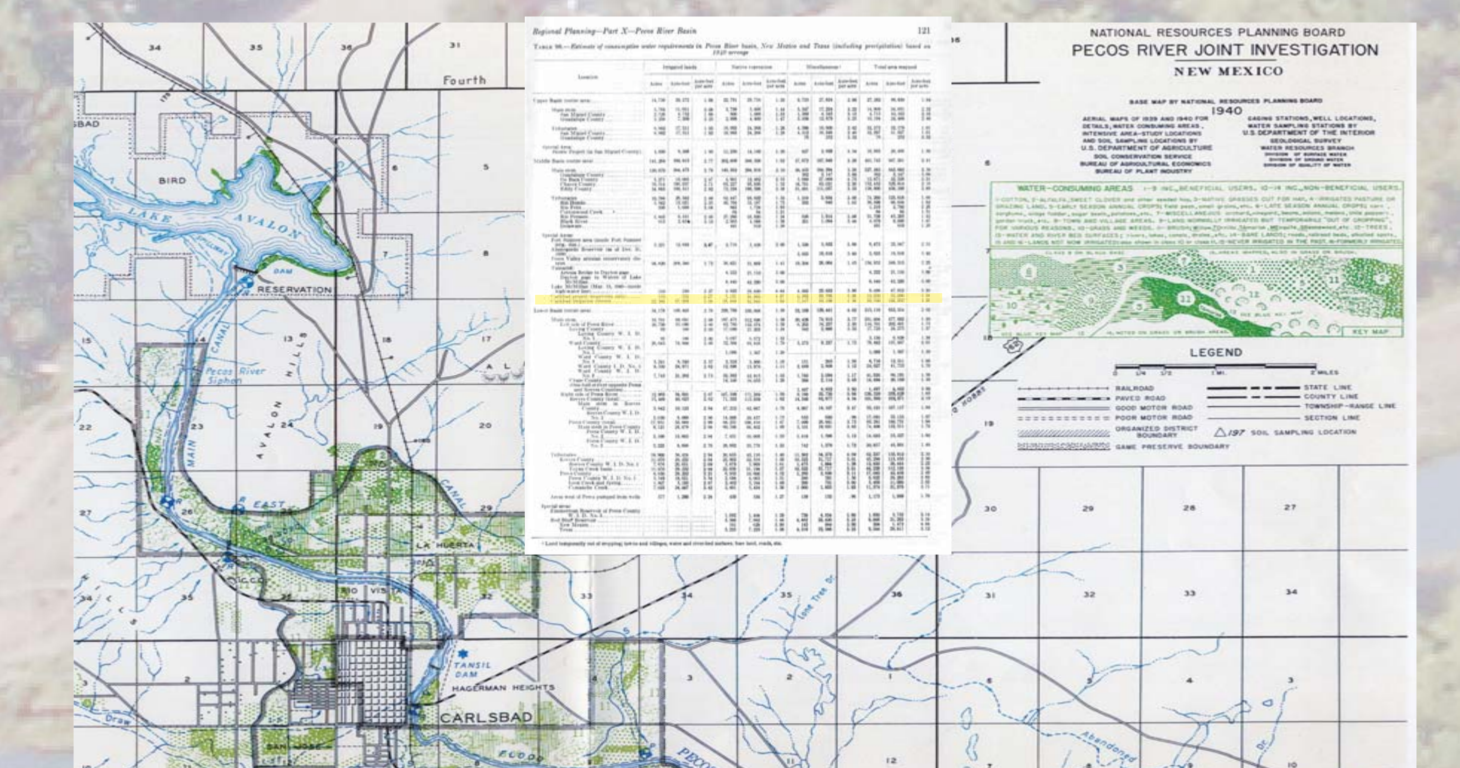


FIGURE 1
PECOS RIVER JOINT INVESTIGATION

CORE COMPONENTS

Model Core Components:

HydroModel: areas including gridded representations of stream, ditch and drain segments, return flow and ET areas.

HydroBudgetRaster: Includes remotely sensed vegetation cover and soil moisture, Surface energy balance components and distributed CU.

HydroBudgetUnits: Accounting units boundaries.

HydroMet: Meteorological station locations and parameters, NEXRAD HRAP cells and PRISM cells.

Time series: Data following the Arc-Hydro schema for model results such as stream leakage, and climate components.

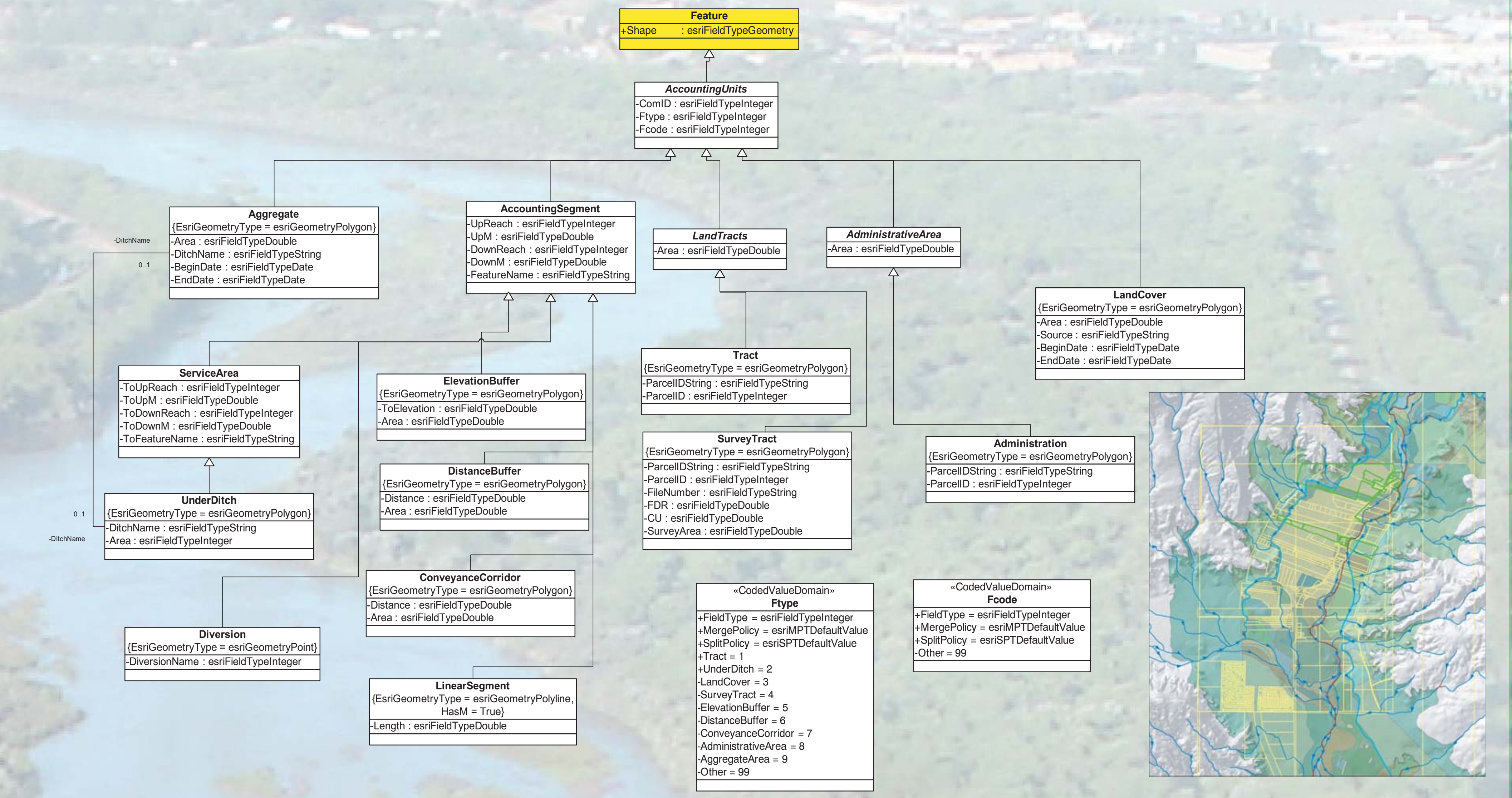
«FeatureDataset» **HydroModelUnits**

«FeatureDataset» **RasterData**

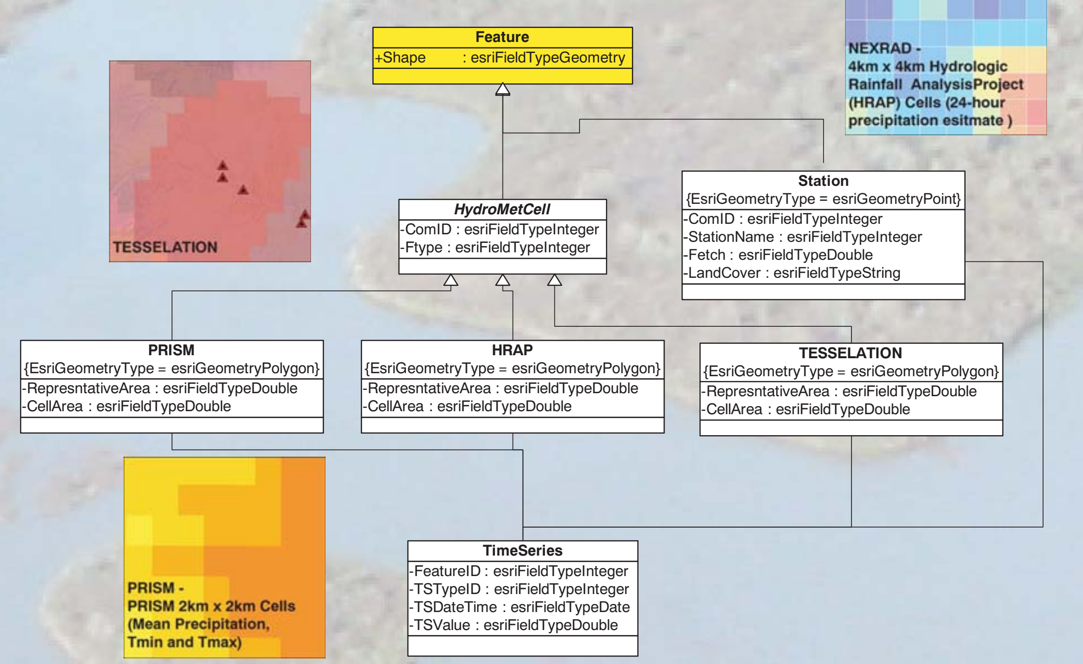
«FeatureDataset» **HydroBudgetUnits**

«FeatureDataset» **HydroMet**

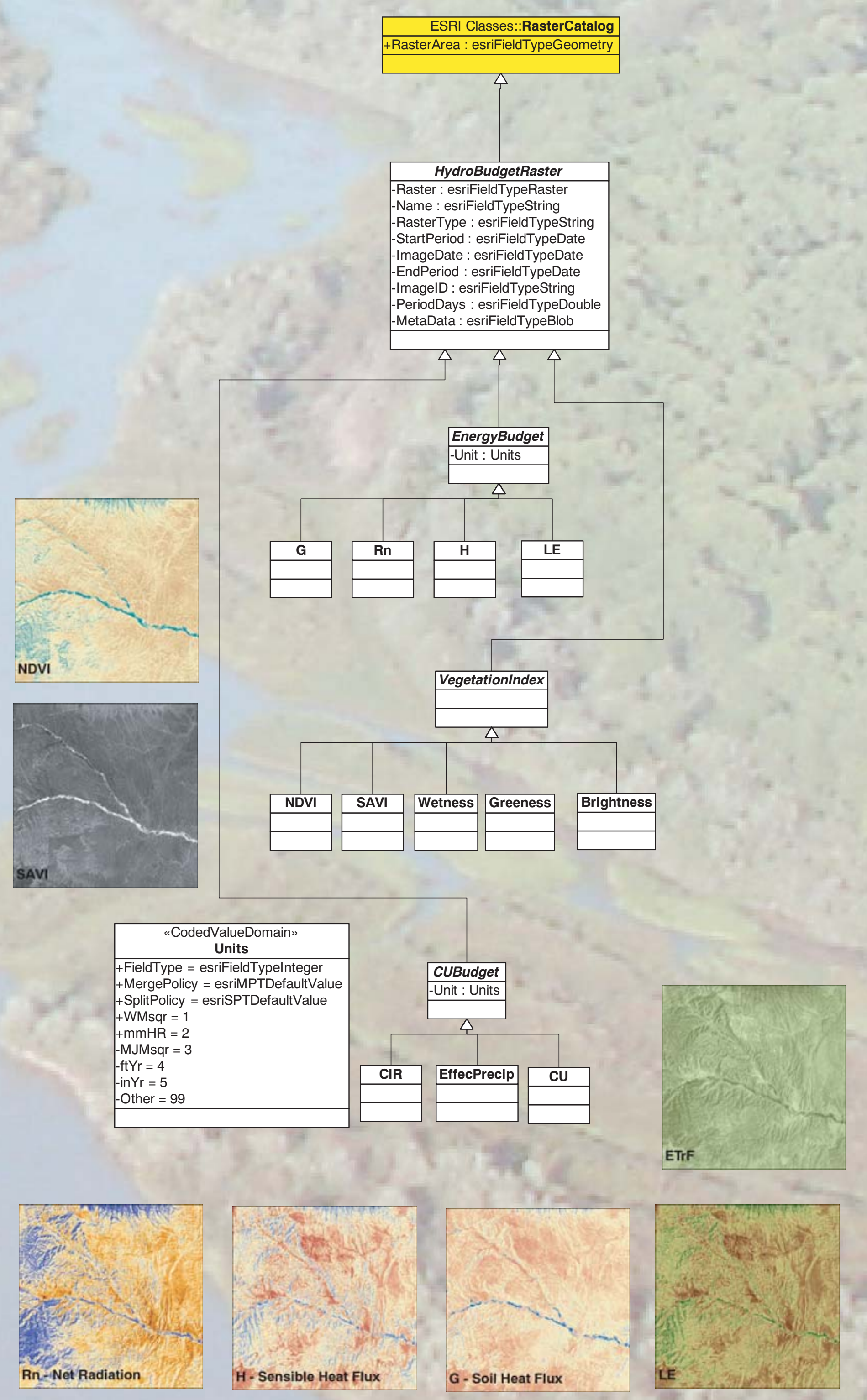
ACCOUNTING UNITS



HYDRO-MET DATA



RASTER DATA



HYDRO MODEL DATA