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May 16, 2003

To: Mike MacDonald

From: Derrel Martin

Re: Description of Method Used to Distribute Pumpage and Surface Water

xc: Republican River Groundwater Modeling Team

The methods used to distribute ground and surface water for the groundwater model are described in this document. As you know few data are available to exactly distribute water to irrigated land. A discussion of the interdependence of these values with recharge computations is included at the end of the memorandum.

Background

In earlier phases of the project we distributed pumpage based on the capacity of individual wells and the amount of land irrigated within a groundwater model cell. We developed routines to compute the fraction of the irrigation application that was consumed for evapotranspiration based on the adequacy of the water supply. The remaining water was partitioned into recharge and surface runoff. We also included methods to compute recharge that occurs during transmission of runoff from fields to water ways. In my opinion those methods provided reliable estimates of the distribution of recharge from precipitation, groundwater and surface water supplies. The method was built upon current knowledge of irrigation hydrology and accurately reflected the performance of systems, soils, cropping patterns and precipitation in the Republican River Basin.

Some issues arose with the methodology:

1) consultants for other states allegedly had difficulty comprehending the method described in previous documentation,

2) the program to distribute the water required significant time to process varying levels of spatial data and to update the distribution when underlying databases were revised, and

3) the method may have resulted in water stress on lands that had lower capacity wells while high capacity wells could have applied excess water.

Other states chose a simpler method to distribute pumpage and surface water delivery. Their computations are based primarily on the amount of land irrigated in a cell. Pumpage is computed based on the theoretical consumptive irrigation requirement (CIR) and an irrigation efficiencies assigned to various types of irrigation systems. The recharge from irrigation is assumed to be a constant percentage of the water applied for specific irrigation systems regardless of the adequacy of the water supply. Water is distributed on a county-level basis. The total pumpage is computed for the county based on enumerated CIR, the fraction of the total irrigated acreage for each type of irrigation system and the efficiencies assigned to each type of irrigation system. It is not clear if the other parties assign specific irrigation types to individual groundwater cells within the county, or if the distribution of pumpage to a specific groundwater cell is simply computed as the fraction of the county-level pumpage based on the quantity of irrigated land that falls within the groundwater cell. I suspect that the latter method is used.

To be analogous with the other states we utilized a county-level distribution for this phase of the project. We computed the volume of pumping based on electrical energy use, pumping power requirements and estimated well discharge based on a correlation to the flow rate recorded at the time of well registration. Our method used a uniform time of operation for wells supplied by a Public Power District. The total volume of water pumped for a county was provided to the states on April 18, 2003. The delivery at that time was based on county data for the number of wells and acres irrigated in the counties in the basin. The values included in the spreadsheets were those utilized by Kansas and Colorado consultants. Apparently those spreadsheets lacked some irrigated land and/or wells in some counties. We corrected that miscalculation and produced the final volumes of pumpage on a county-level basis in early May. The states have agreed to those annual pumpage volumes.

Irrigated Land

The methodology is based on a uniform distribution of ground and surface water across the county for three types of irrigated land. The method uses the number of acres in the county that are irrigated only with groundwater, those irrigated only with surface water and those lands where ground and surface water are commingled into a single supply. The first step of the process involves determining the status of lands that are irrigated. A geographic information system (GIS) was used to overlay the location of irrigation wells and polygons of lands that received surface water. A buffering distance of 800 feet was used to determine if an individual polygon was assigned to the sole-source surface water category or if the land was assigned to the commingled category. The distance of 800 feet was determined based on the amount of the land under the Central Nebraska Public Power and Irrigation District (CNPPID) that receives a commingled supply. The amount of commingled land under the CNPPID project has been estimated to be 35% of total irrigated land served by the project. The buffering distance of 800 feet produced an amount of commingled land nearly equal to the 35% fraction for the CNPPID project. Subsequently, the 800-ft buffering distance was used across the entire portion of the basin in Nebraska. Polygons that were not identified as commingled land were assigned to the sole-source surface water irrigated land category. The amount of sole-source groundwater irrigated land was computed by subtracting the amount of land that received surface water from the total amount of land irrigated in the county, as based on corrected National Agricultural Statistical Service (NASS) estimates. As has been previously explained, the NASS data are not reliable for the irrigated area prior to 1955 and other methods were used to estimate irrigated area for that period. That determination has been described previously and will not be repeated here. The results of these computations produced that amount of land in each county that was irrigated only with groundwater, only with surface water and that received a commingled supply.

Groundwater Distribution Methodology

The total amount of pumpage for the county was determined from the electrical power records as has been previously discussed. The method that we used to distribute both ground and surface water are based on the assumption that the water is uniformly distributed across the land in each of the three categories. Thus within a county, we assume that the volume of groundwater applied per acre of irrigated land (*i.e.*, the irrigation depth) is uniform across sole-source groundwater land in that county. Likewise, the depth of irrigation for commingled lands is uniform across the county for a given year, and finally the depth of irrigation for sole-source surface water is uniform. The depth applied to each category of land is not the same, but the depth within a category is the same.

The total volume of groundwater pumped is applied either to the sole-source groundwater land or to the commingled land. Furthermore, the volume of groundwater pumped is computed from the acreage of

$$Vp = Vg + Vc = Ag \times Dg / 12 + Ac \times Dc / 12$$

each category times the depth of water applied to each acreages:
where; Vp is the total volume of groundwater pumped, acre-feet; Vg is the volume of groundwater

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pumped on sole-source groundwater areas, acre-feet; Vc is the volume of groundwater pumped on commingled lands, acre-feet; Ag is acres of sole-source groundwater irrigated land; Ac is the acreage of commingled land; Dg is depth of groundwater applied to sole-source groundwater irrigated land, acre-inches/acre and Dc is depth of groundwater applied to commingled land, acre-inches/acre.

Since commingled land receives both ground and surface water, it was deduced that the average depth of groundwater applied to commingled land was a fraction (f_g) of that applied to lands that only received groundwater, (*i.e.*, $Dc = f_g H Dg$). Then, the depth of groundwater applied to sole-source groundwater

$$Dg = \frac{12\ Vp}{Ag + f_g\ Ac}$$

lands was determined from:
Once the depth of water applied to lands irrigated only with groundwater was determined, the uniform depth of groundwater applied to commingled lands was computed.

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The ratio of the depth of groundwater applied to commingled land to the depth applied to sole-source groundwater irrigated land for each county for the period of simulation is provided in Table 1. Results in the table illustrate that a ratio of 0.5 was used for most counties. Larger values were used for some counties and years where a higher ratio was judged to provide more reliable water application.

The depth of irrigation water applied to land where groundwater is the sole source is summarized in Table 2. Irrigation depths that were smaller than six inches, or larger than thirty-six inches, were highlighted in the table. Results show that the majority of small irrigation depths occurred before 1958. The years of 1962 and 1993 also resulted in a significant number of counties with irrigation depths smaller than six inches. However, precipitation during these years was significantly larger than average across the basin. Irrigation depths larger than 36 inches occur infrequently for sole-source groundwater irrigated land. Large depths only occur for Keith County in 1959, 1968 and 1970. The years of 1968 and 1970 were amongst the driest years in the western portion of the basin. Keith County is only partially within the Republican Basin and apportioning land and water in partial counties can lead to disproportionate values in some years. However, since only a small portion of Keith County is in the basin, and since the land is near the northern boundary of the groundwater model domain, the few years of large values were considered to be acceptable. The average depth of water application for Keith County are quite reasonable as summarized in the lower portion of Table 2.
The rest of the annual irrigation depths for sole-source groundwater irrigated land that exceed 36 inches are located in Webster County. There are a series of years between 1955 and 1968 where the depth applied exceeds 36 inches. After 1968 the depth is less than 36 inches for all but 1974, also a very dry year. After 1977, the depth of water applied in Webster County is smaller and more consistent with surrounding counties.

The depth of groundwater applied to commingled land is listed in Table 2. Since these values are proportional to the depth applied to sole-source groundwater land, the same pattern of applications as in Table 1 is evident. The annual depth of groundwater applied to sole-source and commingled land for all counties and years are plotted in Figures 1 and 2. These graphs illustrate the frequency of irrigation amounts for the entire basin.

The total depth of ground and surface water applied to the commingled land is listed in Table 3 with a graph of the results in Figure 3. The total depth of water applied to commingled lands exceeds 36 inches more often for the boundary counties of Dawson, Deuel and Keith counties. The total depth applied for commingled land in Nuckolls and Webster counties also exceeds 36 inches during some years.

Surface Water Distribution Methodology

The amount of surface water supplied to either sole-source surface water or commingled lands was determined from records for private and federal irrigation projects. We utilized the data provided by HDR, Inc. Surface water supplies were distributed similar to groundwater. The total amount of surface water available within a county was determined from water supply records for private and government

$$Vw = Vs + Vc = As \times Ds / 12 + Ac \times Dc / 12$$

owned irrigation projects. The water balance for surface water is given by:
where; Vw is the volume of surface water applied, acre-feet; Vs is the volume of surface water applied to

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land with surface water as the sole-source, acre-feet; As is the area of land supplied with surface water as a sole source, acres and Ds is the depth of water applied to the sole-source surface water land, inches. Since commingled land receives both ground and surface water, the average depth of surface water applied to commingled land was a computed as a fraction (f_w) of that applied to lands that only received surface water, (*i.e.,* $Dc = f_w H Ds$). The depth of surface water applied to sole-source surface water land

$$Ds = \frac{12\ Vw}{As + f_w\ Ac}$$

was determined from:
Once the depth of water applied to lands irrigated only with surface water was determined, the uniform depth of surface water applied to commingled lands was computed. Results for the ratio of commingled to

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sole-source surface water application depths, depths of surface water applications for sole-source and commingled surface water and the accompanying graphs are included in Tables 6 through 9 and Figures 4-5 respectively.

Processing of Information

The data for the distributed irrigation water supply datasets are contained in four Access databases and two Excel spreadsheets on two compact disks which were sent to members of the Groundwater Technical Committee on May 16, 2003. The data were processed in four main steps to produce the distributed irrigation water supply datasets.

1. Step 1 was to determine the available area per cell to which irrigated acreage could be distributed. The distribution constraints for this included: 1) Ensuring that the assigned phreatophyte acreage, urban and water acreage as processed from the National Landuse Coverage Dataset (NLCD) produced by the United States Geological Survey (USGS), and assigned surface water irrigated acreage did not exceed 640 acres per cell; and 2) Ensuring that the total distributed acreage would match the previously provided annual county values. In the course of this process phreatophyte acreage from nine cells was moved to adjoining cells. The quantity of acreage moved ranged from 0.68 acres to 134.25 acres per cell. This work was accomplished using database PhreatoWorkRoutines.mdb.

2. Step 2 was to distribute irrigation water as described in the previous section. This was achieved using the spreadsheets AcInDistribution.xls and AcInDistribution_SW.xls. These spreadsheets calculate a distributed application depth at a scale consistent with the scale of currently available source data. The spreadsheet AcInDistribtion.xls provides application depths of groundwater. The spreadsheet AcInDistribution_SW.xls provides the depth of surface water applied to sole-source surface water irrigated lands in the same manner. The approach recognizes that the GIS coverages of surface water polygons are not exact representations of irrigated fields and also recognizes the complexities of some on-farm water distribution systems are beyond the scale of this model. The information from these spreadsheets was imported into DistribWaterRoutines.mdb and organized into a format usable by the distribution program.

3. Step 3 was to distribute irrigated acreage to neighboring cells such that no cell contained more irrigated area than available for irrigation. The quantity of irrigation water was also distributed using the application depths calculated as part of Step 2. The program which

distributes acres and irrigation water is a Visual Basic (VBA) module within CellDistributionRoutines.mdb named "CellDistribution". The program looks to find cells which have assigned acreage greater than 640 acres. Once it locates the cell with the largest assigned area over 640 acres, the program attempts to evenly distribute the acreage and water to the nearest eight cells. If there is insufficient acreage in the nearest eight cells, the program searches the nearest 24 cells. If there is insufficient acreage to evenly distribute the overage to the nearest 24 cells, then the cell is listed in the table named "SkippedCells" and must be manually distributed. Due to the constraint requiring that county acreage be conserved, the nearest cells must reside in the same county as the cell with the acreage overage. The program successfully distributed the acreage and pumpage estimates for all cells and years with the exception of one cell for four years: cell 54-251 was distributed using the query series named "ManualUpdates…" to cells 50-250 and 50-251 in years 1989, 1994, 1996, and 2000.

4. Step 4 was to format the data for use by others. Database DataFormatting.mdb was used for this purpose. The four text files transmitted to the FTP site were exported from this database.

Summary

The data encompassed at this phase includes the correct annual pumping on a county basis and the distribution of the water to lands irrigated in that county. To our knowledge these data are essentially final. We understand that HDR, Inc. is cleaning up some records for surface water deliveries and data for irrigators that pump directly from streams. It is our understanding that these data adjustments are relatively minor and should not change our results materially.

Our data show that irrigation water applications exceed requirements in some years. This is the result of using independent datasets for the amount of groundwater pumped, surface water delivered and the amount of land irrigated. Of course this frequently happens in irrigated agriculture. Applications that exceed the irrigation water requirement result in deep percolation within the field and provide recharge larger than comprehended by the other states when they developed their recharge procedures and as implemented in the settlement for irrigated land. We had accounted for this effect in our previous procedures, but the current methodology that is being proposed, *i.e.*, where irrigation recharge is a constant percentage of the irrigation amount and only precipitation recharge rates vary from year to year does not adequately address our pumpage values. It is important to include methodologies that address the increased recharge that results when irrigation application exceed water requirements. The methodology that includes direct irrigation recharge as described in the settlement needs to be combined with an indirect method that accounts for increased recharge when applications exceed requirements. The technique of using the total water application (*i.e.*, adding precipitation and irrigation) should help account for this omission. Without such methods water will be pumped that is not use for crop water use and that does not recharge the aquifer. It would be unreasonable to assume that such water would occur as direct runoff to water ways. If such methods are not included we will make significant water balance errors in some years especially in the eastern part of the basin.