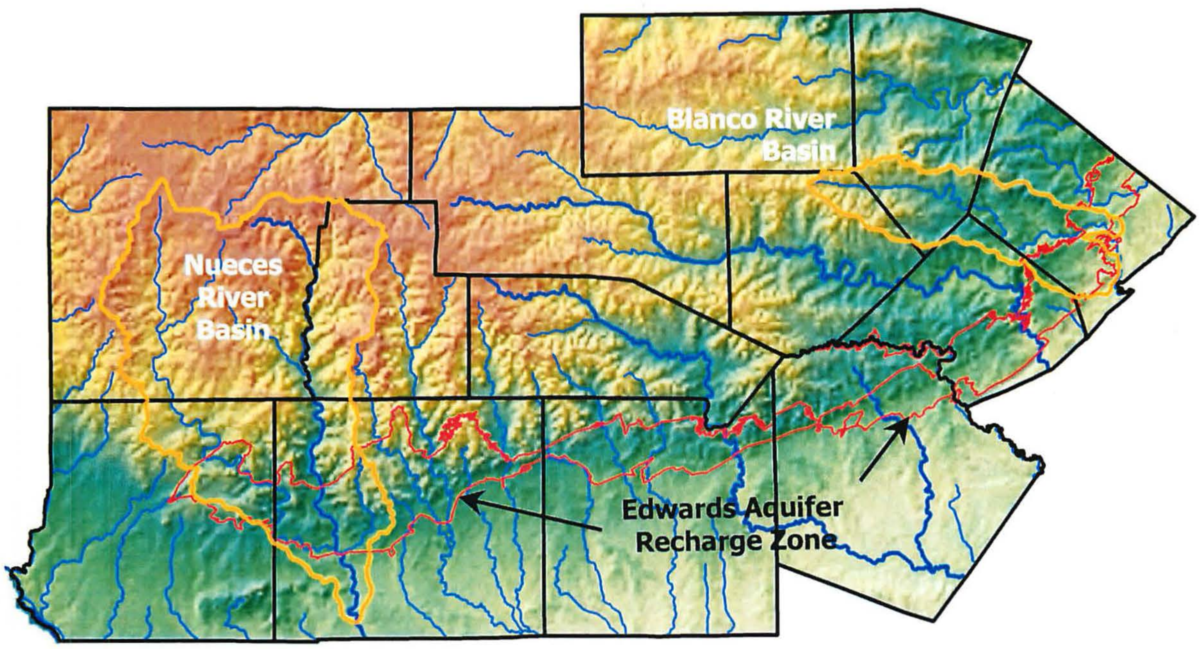
EDWARDS AQUIFER AUTHORITY

Assessment of Recharge Benefit from Enhanced Rainfall



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June 2003

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1. Executive Summary

LBG-Guyton Associates has used pilot recharge models (developed using HSPF (Hydrologic Simulation Package Fortran)) for the Nueces and Blanco River basins to estimate the total amount of increased recharge to the Edwards aquifer during the 1999, 2000, and 2001 Precipitation Enhancement Program (PEP) seasons. Woodley Weather Consultants (WWC)(2002) provided estimates of rainfall and seeding-induced rainfall increments for the Nueces and Blanco basins during the 1999, 2000, and 2001 seasons. These estimates of increased precipitation were used as a basis for simulating the impact of the PEP on aquifer recharge.

Modeling results indicate the total increased aquifer recharge during 1999, 2000, and 2001 in the Nueces basin was 663, 655 and 654 acre-feet per year respectively, which represents a 0.45, 0.34 and 0.19 percent per year increase respectively. The total increased recharge during the three-year period was 1,972 acre-feet, or 0.29 percent in the Nueces basin. In the Blanco basin, the increased aquifer recharge was 152, 179, and 1,001 acre-feet per year respectively, which represents a 0.44, 0.56, and 1.92 percent per year increase respectively for the Blanco basin. The total increased aquifer recharge during the three-year period was 1,332 acre-feet, or 1.13 percent in the Blanco basin. About half of the Nueces basin is in the cloud seeding zone, which may have reduced the impact of the PEP with regard to aquifer recharge in that basin.

WWC (2002) indicates that the enhanced precipitation during the 1999, 2000, and 2001 seasons could have been increased if more cloud seeding had been performed. To simulate the effect of potentially greater enhanced precipitation, Scenario 1 was simulated. Scenario 1 assumed that the enhanced precipitation was equal to one inch on each of the days for which cloud seeding was considered successful (i.e., five days for Nueces basin and eight days for Blanco basin during the 3-year period). Scenario 1 modeling results indicate that the total increased aquifer recharge during 1999, 2000, and 2001 in the Nueces basin was 4,123, 754, and 2,029 acre-feet per year respectively, which represents a 2.8, 0.4, and 0.6 percent per year increase respectively in the total recharge for the Nueces basin. The total increased recharge during the three-year period was 6,906 acre-feet, or 1.0 percent in the Nueces basin. In the Blanco basin, the increased aquifer recharge was 1,717, 550, 2,828 acre-feet per year respectively, which represents a 5.0, 1.7, 5.5 percent per year increase respectively in the total recharge for the Blanco basin. The total increased aquifer recharge during the three-year period was 5,095 acre-feet, or 4.2 percent in the Blanco basin.

Limitations and assumptions of the modeling methodology are discussed in this report. Important factors affecting the evaluation of the PEP are the spatial and temporal accuracy of the precipitation data and the inability of the pilot models to simulate hydrology in the contributing zones of the watersheds that recharge the aquifer. In order to evaluate the PEP in the future, it is recommended that appropriate resources be applied to collecting and evaluating precipitation data, especially during the PEP season. In addition, future models should simulate the hydrology of the entire watershed instead of just the recharge zone.

2. Introduction

The Edwards Aquifer Authority (the Authority) is interested in determining whether cloud seeding (i.e., PEP) has been effective to enhance rainfall and likewise determine the impact of any increased precipitation on recharge to the Edwards aquifer. To evaluate the effectiveness of PEP to increase aquifer recharge, pilot recharge models developed by HDR (2002) for the Nueces and Blanco River basins were employed. The Nueces and Blanco River basins lie on the western and eastern edges of the San Antonio section of the Edwards aquifer, respectively, as shown in Figure 1. The models were called "pilot" models because they were developed to see whether or not HSPF watershed models operating on a daily timestep would be helpful for estimating daily recharge to the aquifer. The two pilot models were designed to simulate the hydrology and aquifer recharge in the Nueces and Blanco watersheds as they traverse the Edwards aquifer recharge zone. The Authority concluded that the resulting pilot models were appropriate for estimating recharge, and the Authority accepted the basic methodology and pilot models as a means of estimating recharge. Therefore, quantitative estimates of increased recharge from the PEP were estimated with the two pilot models. The Authority is currently developing HSPF recharge models for the seven interior basins, but they have not yet been completed.

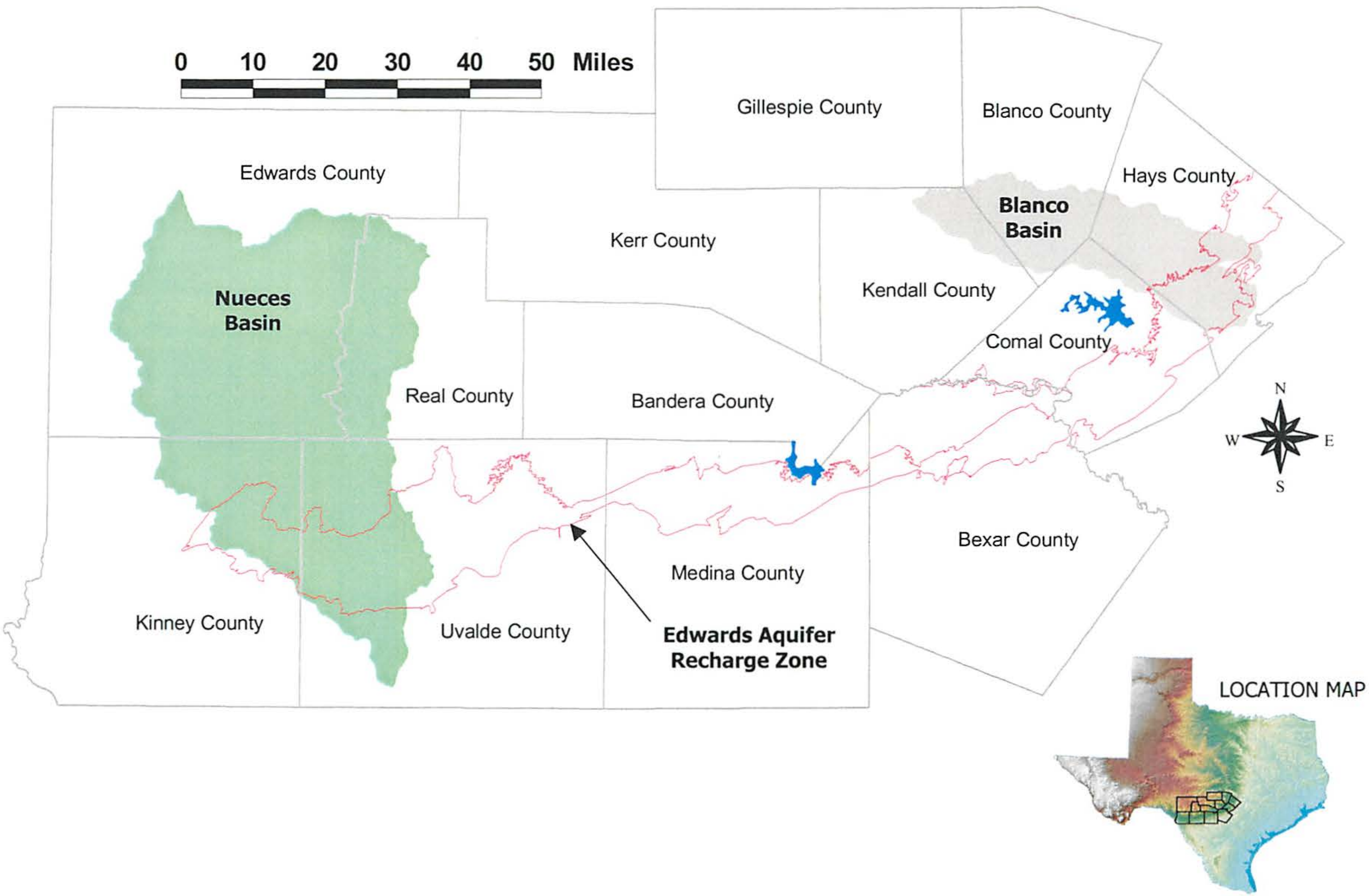
WWC (2002) estimated rainfall and seeding-induced rainfall increments for the Nueces and Blanco watersheds during the 1999, 2000 and 2001 PEP seasons. These estimates of increased precipitation, along with other hydrologic data such as streamflow measurements, evaporation, and water levels in wells have been used as a basis for simulating the impact of PEP on aquifer recharge.

3. Updating the HSPF Model Datasets

The pilot recharge models for the Nueces and Blanco River basins were originally developed to simulate flow through the end of 1998. Therefore, in order to use the models to estimate recharge during the 1999, 2000 and 2001 PEP seasons, the pilot models had to be updated to include the input data for those years. The following sections describe the data sources and methods used to update the models for this study.

3.1 Precipitation and Enhanced Precipitation

Estimates of the total rain volume and the volume of the seeded increment (i.e., enhanced precipitation) were obtained from WWC (2002) (Tables 2 and 3 respectively for Nueces and Blanco basins). The approximate depth of the enhanced precipitation was calculated by dividing the volume of the seeded increment by the drainage area as reported in the WWC (2002) report. The total drainage areas of Nueces and Blanco basins reported by WWC (2002) are 1,734 mi^2 and 484 mi^2, respectively. HDR (2002) reports the drainage areas of the recharge zone of Nueces and Blanco basins are 430 mi^2 and 57 mi^2 respectively, which account for about 23% and 14% of the total drainage area of each basin.



Location of Nueces and Blanco Basins

FIGURE 1

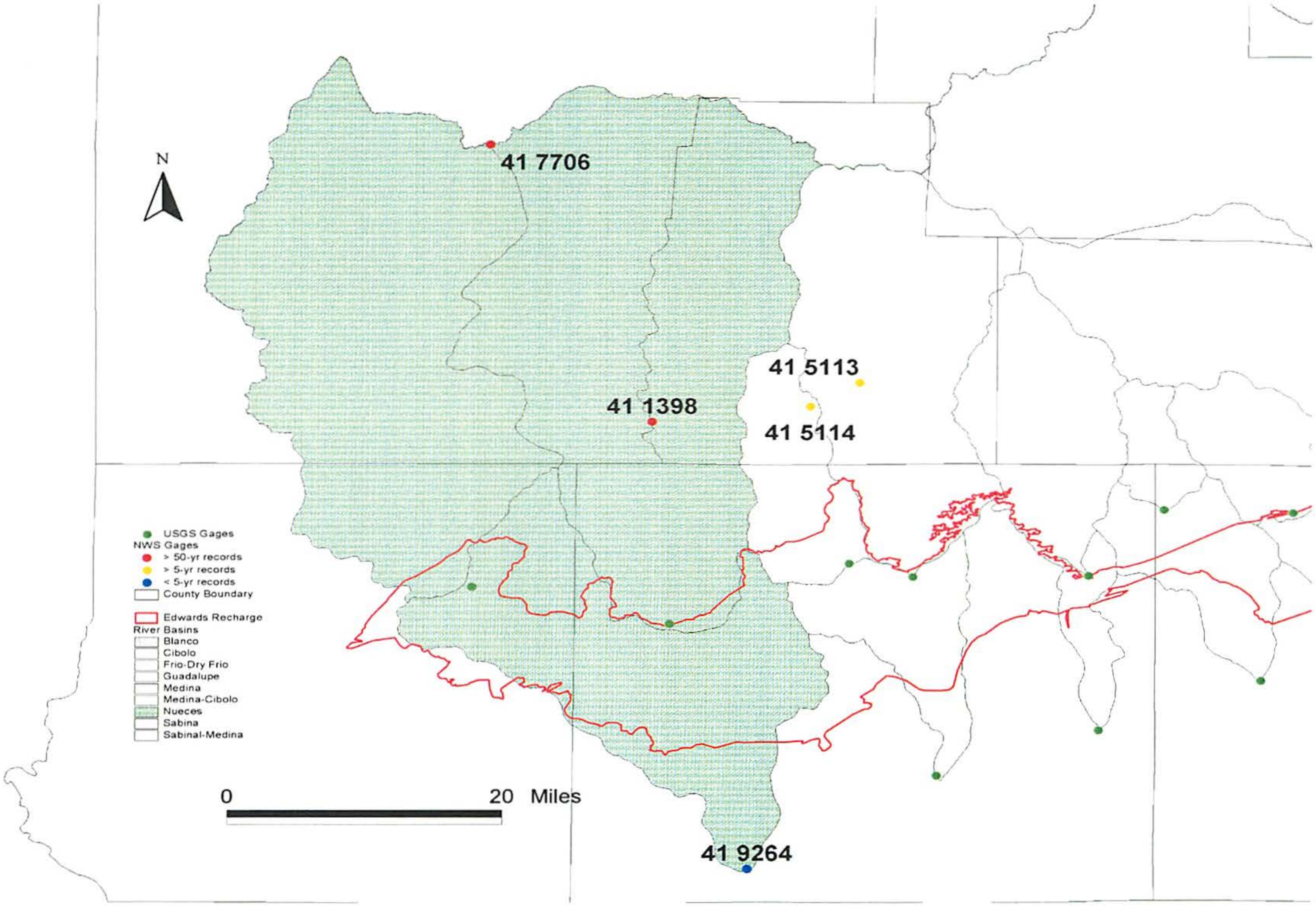
Table 1 lists the days on which the estimated enhanced precipitation was considered reliable by WWC (2002). It is assumed that cloud seeding did not produce a significant increase in precipitation on other cloud seeding dates.

Table 1. Summary of Estimated Rain Volumes and Seeded Increments

Date	Total Precipitation (ac-ft)	Enhanced Precipitation (Seeded Increment) (ac-ft)	Enhanced Precipitation (Seeded Increment) (inches)
Nueces Basin			
6/14/1999	3,296	1,142	0.0123
7/10/1999	16,648	5,767	0.0623
9/14/2000	4,832	1,737	0.0187
8/30/2001	1,142	396	0.0042
8/31/2001	20	7	0.000074
Blanco Basin			
7/10/1999	9,957	3,449	0.1335
7/11/1999	5,129	1,777	0.0688
7/21/1999	9,507	2,995	0.1160
7/30/2000	2,271	716	0.0277
9/14/2000	6,881	2,384	0.0923
8/26/2001	5,127	1,615	0.0625
8/31/2001	908	315	0.0121
9/5/2001	10,459	3,343	0.1294

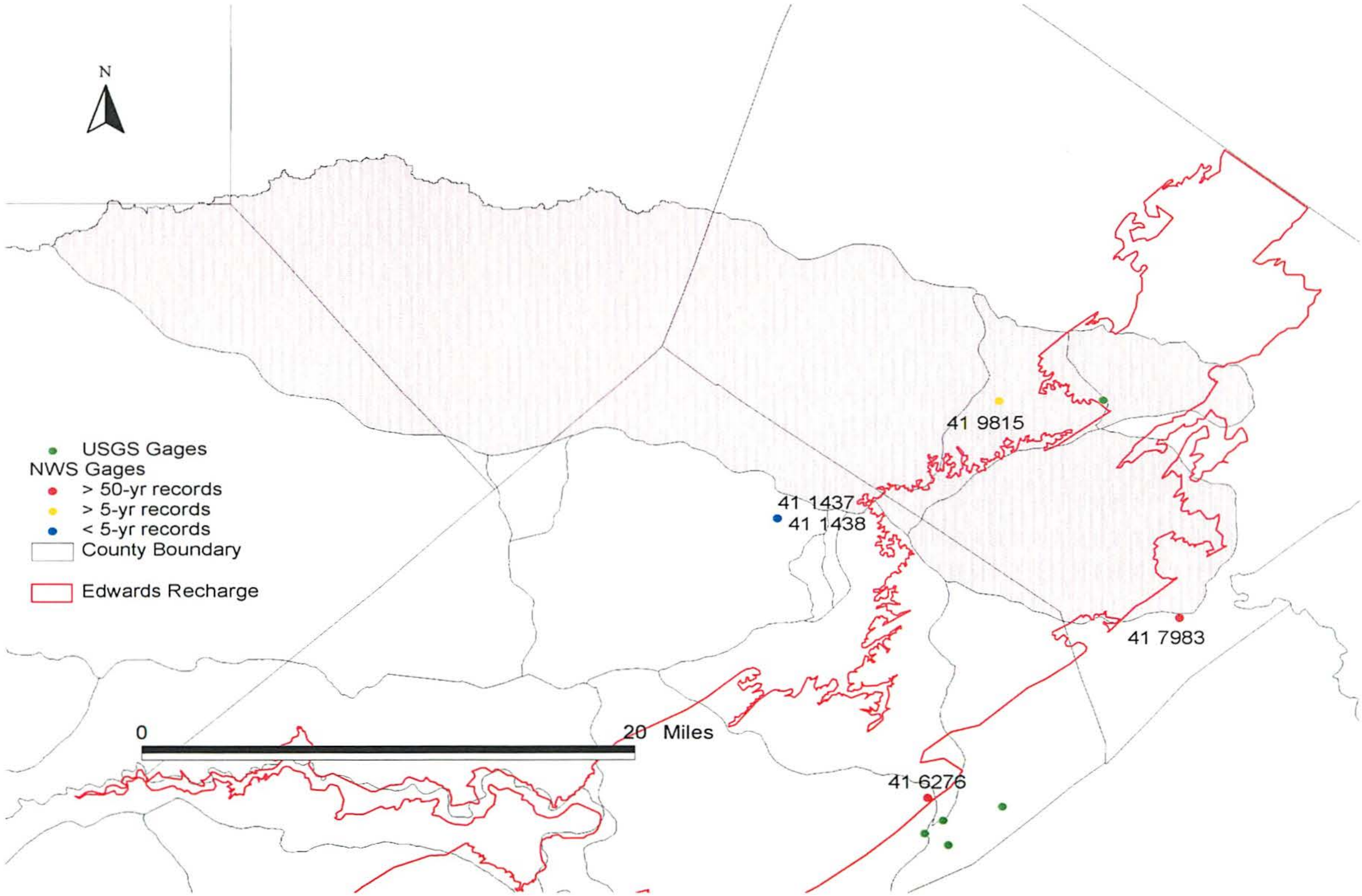
It should be noted that the seeded increment would be larger if it were assumed that the enhanced precipitation fell on only a portion of the watershed, which was probably the case on most days. This would result in a larger seeded increment because the watershed area would decrease. In addition, if the seeded increment fell mainly on the recharge zone, the resulting impact on aquifer recharge might be significantly different than if the seeded increment fell in the contributing zone. In this study, the depth of the seeded increment was calculated by assuming that the seeded volume fell evenly over the entire watershed because there was no reliable information that could be used to spatially distribute the rainfall. This convention produces a conservative (i.e., relatively smaller) estimate of the impact of cloud seeding on aquifer recharge.

The HSPF pilot models require daily precipitation data for each basin. Although WWC (2002) estimated precipitation for each day during each PEP season, it was determined that it was more appropriate to use measured precipitation from established gages because that was more consistent with the methodology used to develop and calibrate the recharge models. Therefore, the data in Table 1 were used to establish the increase in rainfall on the days when cloud seeding was determined to be successful. To estimate the precipitation other days during the simulation period, National Weather Service (NWS) precipitation data was compiled for gages in and around the Nueces and Blanco basins. Figures 2 and 3 show the location of NWS gages in the Nueces and Blanco basins, respectively. Data from the Authority's precipitation gage network could not be used to estimate basin precipitation because the data from the network was only reliable during 2001, which only represents one-third of the simulation period.



NWS Precipitation Gages in the Nueces Basin

FIGURE 2



NWS Precipitation Gages in the Blanco Basin

FIGURE 3

If possible, NWS gage 419264 was used to estimate precipitation in the Nueces basin. On some days, precipitation data from gages 411398, 415113, and 415114 were used to augment the precipitation record. For the Blanco basin, NWS gage 417983 was typically used to estimate precipitation, and data from gages 411437, 416276, 419815, and 417983 were used to augment data as necessary. It should be noted however, that measured precipitation in these gages was sometimes zero on days when WWC (2002) estimated a positive precipitation for the basin. This finding is not surprising because the Nueces basin is relatively large, and because the precipitation gages are almost 30 miles apart. Therefore, the gages sometimes register different amounts of rainfall on the same day. Because the NWS data indicated zero rainfall on some days when a seeded increment was calculated, the observed precipitation data was assumed to be the non-enhanced precipitation data for input to the HSPF model. Although this convention may seem backwards, adopting the seeded increment as the enhanced rainfall on days when the observed precipitation was zero would lead to negative precipitation estimates for the non-enhanced precipitation estimate. This convention is also reasonable because the seeded increment is usually a relatively small value. Therefore, the seeded increment estimated by WWC (2002) was used as an estimate of the amount of increased precipitation that was added to the observed precipitation to determine the total enhanced precipitation for the basin on a particular day. Thus, there are two precipitation datasets (non-enhanced and enhanced) to use as input for the HSPF model in each basin, as summarized in Table 2.

Table 2. Non-Enhanced and Enhanced Precipitation on Seeded Days

Date	WWC (2002) Estimate of Seeded Increment (inches)	NWS Precipitation Measurement (Inches) (Used for non-enhanced simulation)	Total Enhanced Precipitation (Inches) (Used for enhanced simulation)
Nueces Basin			
6/14/1999	0.0123	0.1	0.112
7/10/1999	0.0623	0	0.062
9/14/2000	0.0187	0	0.0187
8/30/2001	0.0042	0.05	0.054
8/31/2001	0.000074	0.06	0.06
Blanco Basin			
7/10/1999	0.1335	1.94	2.07
7/11/1999	0.0688	0	0.07
7/21/1999	0.1160	0.32	0.44
7/30/2000	0.0277	0.02	0.05
9/14/2000	0.0923	1.37	1.46
8/26/2001	0.0625	1.09	1.15
8/31/2001	0.0121	0.37	0.38
9/5/2001	0.1294	1.18	1.31

3.2 Daily Streamflow

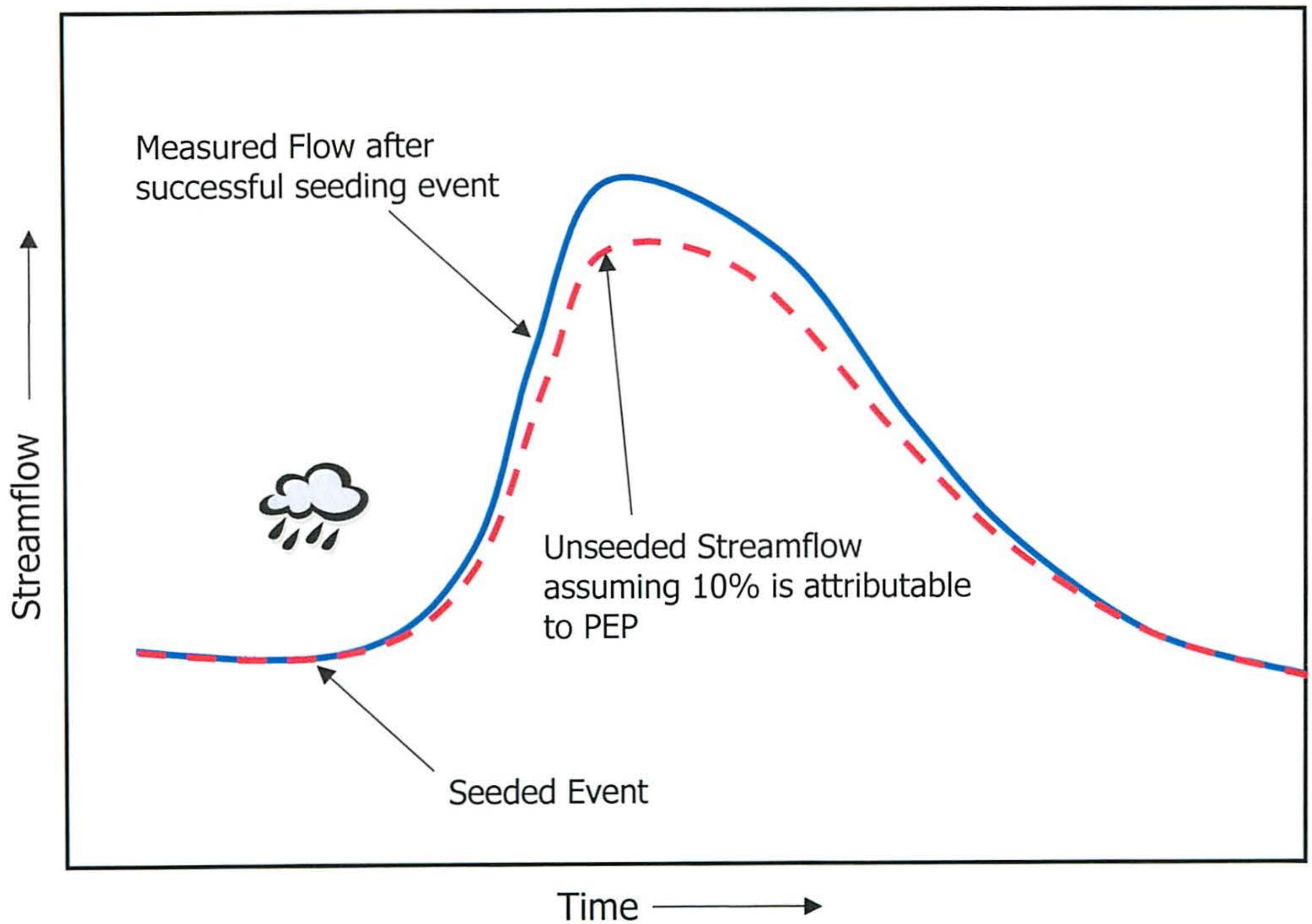
The HSPF pilot models also require daily streamflow data for each basin as input to the model. Daily streamflow data were compiled from the United States Geological Survey (USGS) website for the period from January 1999 to December 2001 for the following USGS gages: 08190000 (Nueces at Laguna), 08190500 (Nueces at Brackettville), 08192000 (Nueces at Uvalde), 08171000 (Blanco at Wimberley), and 08171300 (Blanco at Kyle).

The pilot HSPF models cannot simulate the effect of the PEP on streamflow above the upstream gages in the Nueces and Blanco Basins because the models do not incorporate the contributing zone above these gages. A complete description of the models is provided by HDR (2002). In order to estimate the full benefit of the PEP, it is most appropriate to include the increase in streamflow from the cloud seeding above the upstream gages in the HSPF models. The portion of the streamflow measured in the upstream gages during the 1999, 2000, and 2001 PEP seasons that was due to successful cloud seeding was estimated by first assessing the percentage of total rainfall (on successful cloud seeding days) that was due to cloud seeding. The percentage of total rainfall attributable to cloud seeding (on successful cloud seeding days) ranged from 3 to 37 percent and averaged 10 percent.

Next, the streamflow measurements after successful cloud seeding events were assessed to quantify the increase in streamflow after those events. If there was a significant increase in measured streamflow after a seeded event, it was assumed that the same percentage of rainfall that could be attributed to cloud seeding was also appropriate as an estimate of the percentage of increased streamflow. For this study, it was assumed that 10 percent of the rainfall in the contributing zone was attributable to successful cloud seeding and therefore that 10 percent of the increased streamflow was due to seeded events. In some cases, the seeded events did not produce any increase in the measured streamflow and in other cases, the measured streamflow increased for up to five days following the seeded events. Figure 4 shows a schematic of streamflow after a successful seeding event that illustrates the concept of estimating the increased streamflow after a successful cloud seeding event. The dashed line in Figure 4 illustrates the streamflow that was used for the "non-enhanced" simulation and the solid line (measured data) illustrates the streamflow that was used for the "enhanced" simulation.

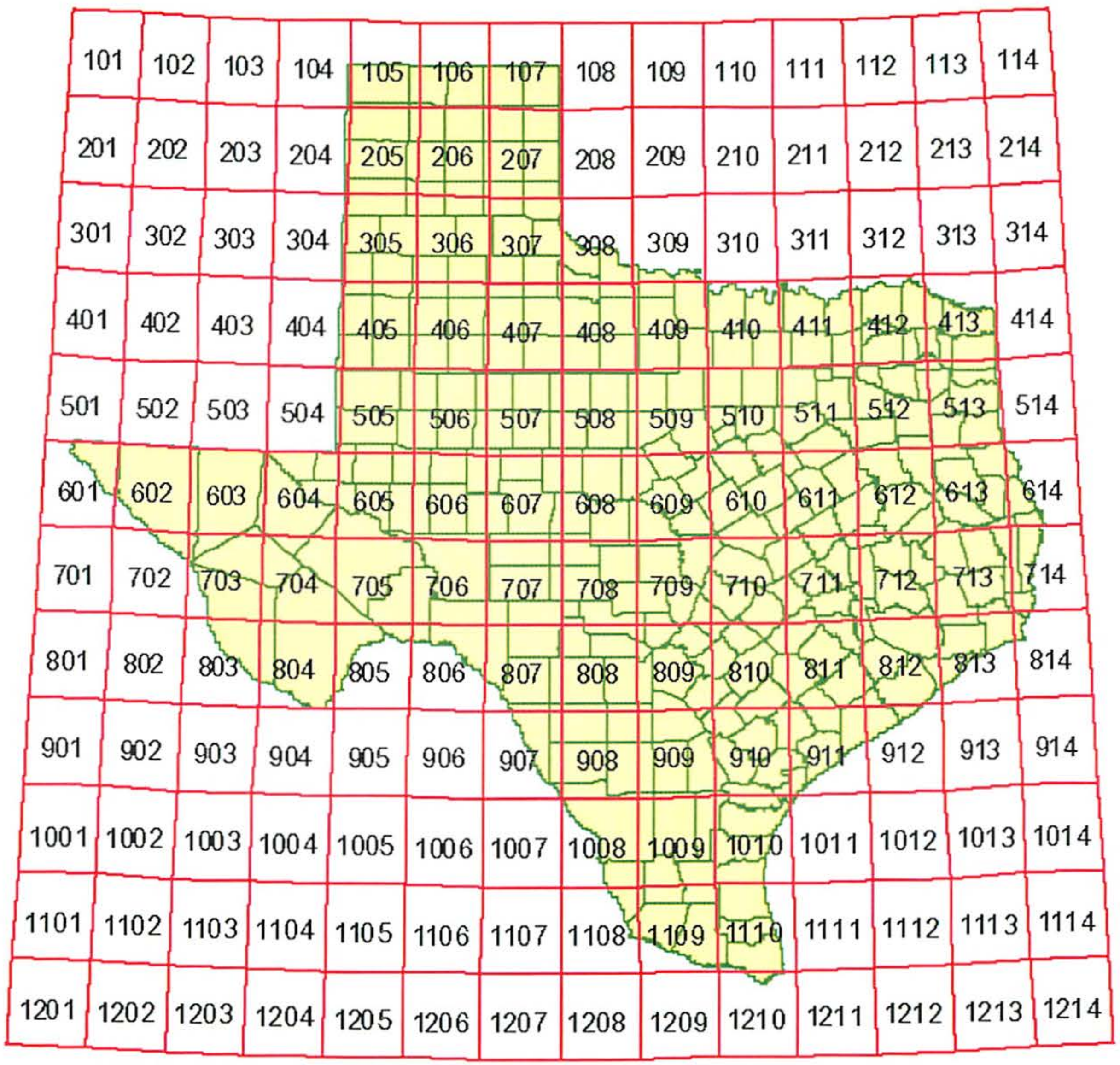
3.3 Evaporation

The HSPF pilot models also require daily estimates of evaporation for each basin as input to the model. The Texas Water Development Board (TWDB) estimates evapotranspiration for the grid system shown in Figure 5. Evaporation data was downloaded from the TWDB website for 1999 and 2000. Data from blocks 807 and 809 were used for the Nueces and Blanco basins, respectively. For 2001, daily evaporation estimates from Texas A&M ET Network were used as input to the model because 2001 data was not available from the TWDB. Figure 6 shows the location of the stations in the Texas A&M network. Data from the Uvalde and San Antonio stations were used for the Nueces and Blanco basins, respectively.



Schematic Diagram of Streamflow Calculations for PEP Simulations

FIGURE 4



TWDB Quadrangle Map of Texas for Evaporation Data

FIGURE 5

Stations in the Texas A&M Evaporation Network

FIGURE 6

3.4 Diversions

The HSPF pilot models also require daily estimates of permitted water right diversions for the Nueces basin as input to the model. In both basins, the permitted water right diversions are typically a small portion of the overall streamflow. Figures 7 and 8 show the comparison of monthly streamflow and water right diversions for 1993 and 1994 in the Nueces basin. Diversion data for the Nueces and Blanco basins has not been compiled for 1999, 2000, and 2001. Therefore, to estimate diversions for the period between 1999 and 2001, diversion data was averaged for the five-year period from 1993 to 1997. Figure 9 shows the monthly diversion data for each year as well as the averaged data that were used in each year of the simulation period (1999 through 2001) in the Nueces basin. Diversions in the Blanco basin are insignificant and therefore were not considered in the pilot models (HDR, 2002).

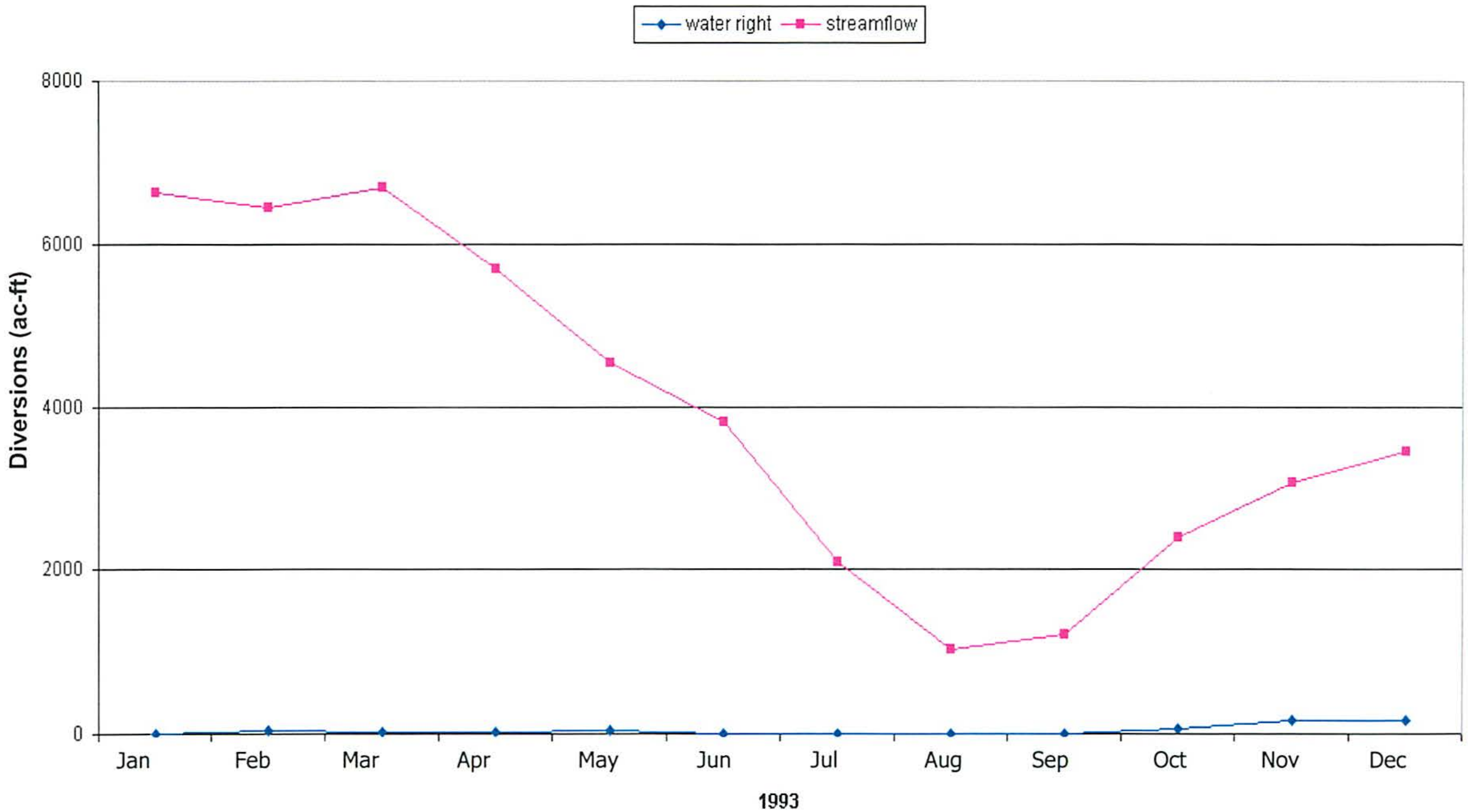
3.5 Leona Gravels in Nueces Basin

The Nueces pilot model makes a special provision to consider inflow from the Edwards aquifer through Leona gravels to the streams in the Nueces Basin (HDR, 2002). Inflows from the Leona gravels were estimated by the same method used by HDR (2002) to obtain extra daily leakage volume from 1999 to 2001. The Authority provided water level data for the monitoring well at Uvalde (#6950302) from 1999 through 2001.

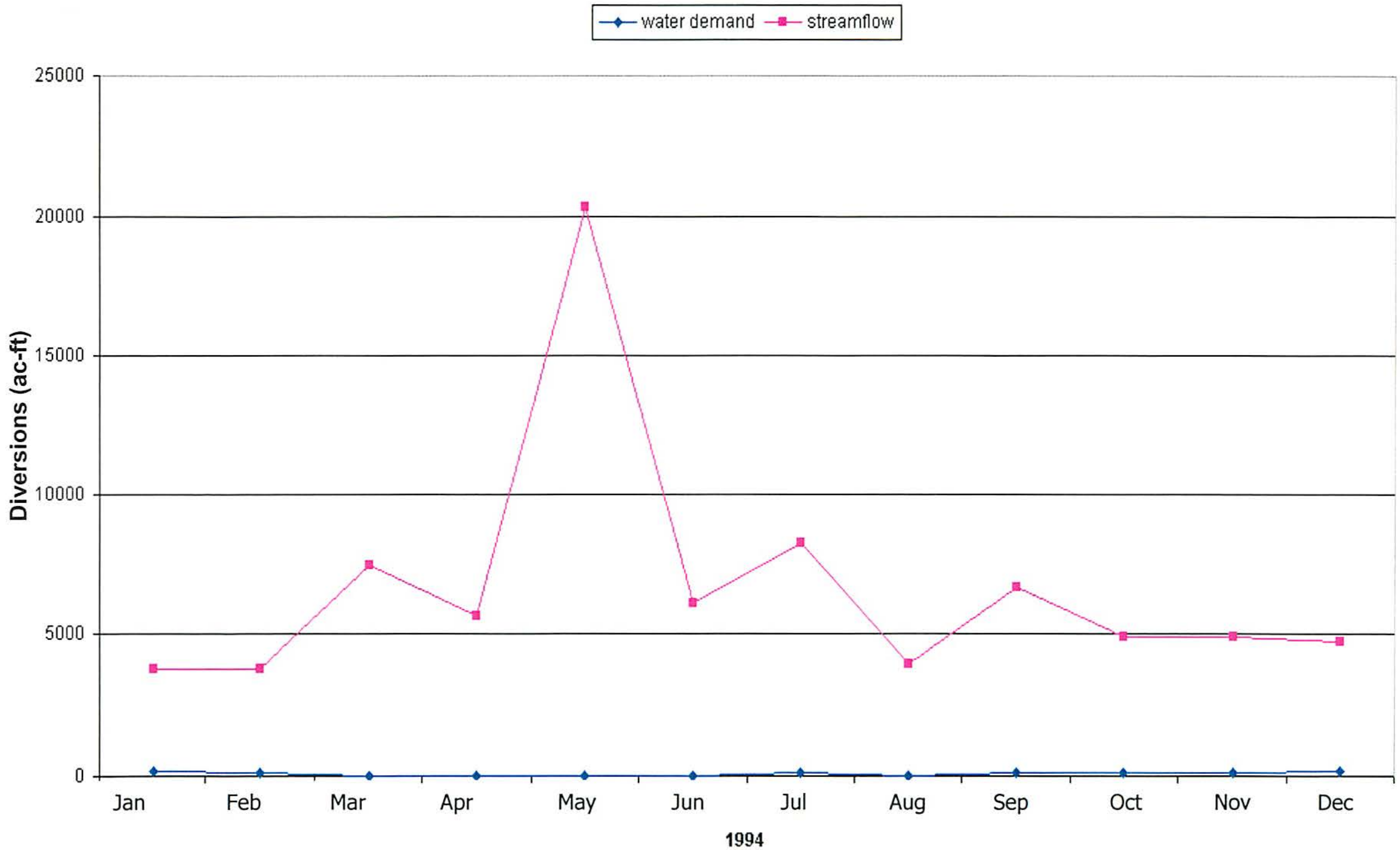
3.6 PEP Simulation Assumptions and Verification Runs

The data sources and assimilation methodology for the PEP simulations were very similar to that used to develop and calibrate the HSPF models. However, for the PEP simulations, it was assumed that one set of precipitation data could be used for each land segment in the basin. Both the Nueces and Blanco basin models contain seven different land segments. HSPF allows each land segment to have a different precipitation record. This flexibility was used for some of the land segments in the pilot models where the data was available and reliable. Because this represents a small modification in the methodology for incorporating precipitation into the models, it is appropriate to compare the methods to determine the impact on model results, especially recharge estimates.

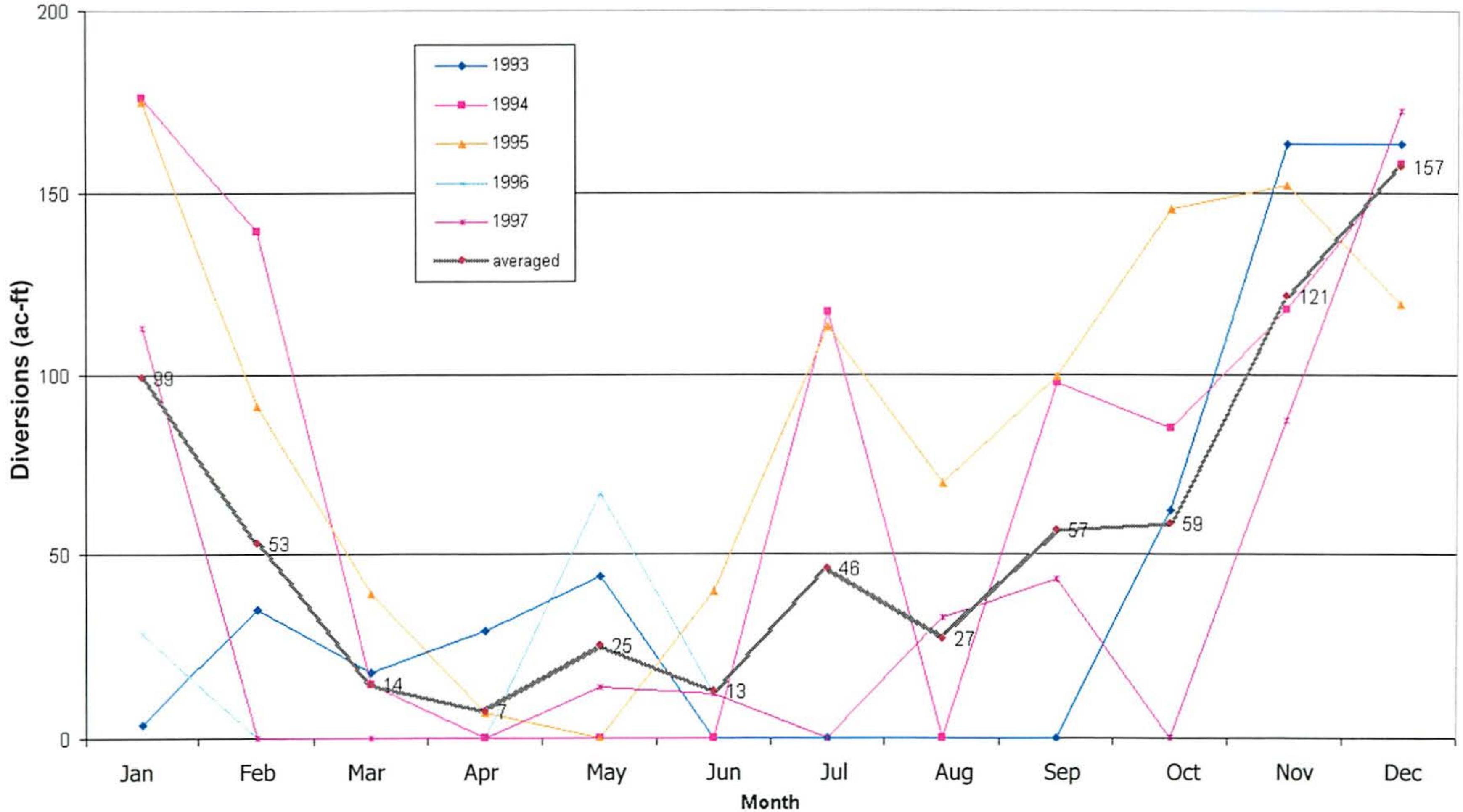
To make this comparison, the method used to compile precipitation and evapotranspiration data for the PEP simulation period was used to develop precipitation datasets for the entire simulation period of the pilot models (1950-1998 in the Nueces and 1956-1998 in the Blanco). To complete the verification simulations in each basin, a single precipitation dataset was applied to all land segments and river reaches in the model. These results were then compared to the original results from the pilot models in each basin to determine how the slightly modified approach would affect simulated recharge. The comparison of the original (pilot) results and the PEP results for the Nueces basin are shown in Figures 10 and 11. The figures indicate that the recharge estimates from the different approaches yield very similar results. Figures 12 and 13 show the comparison



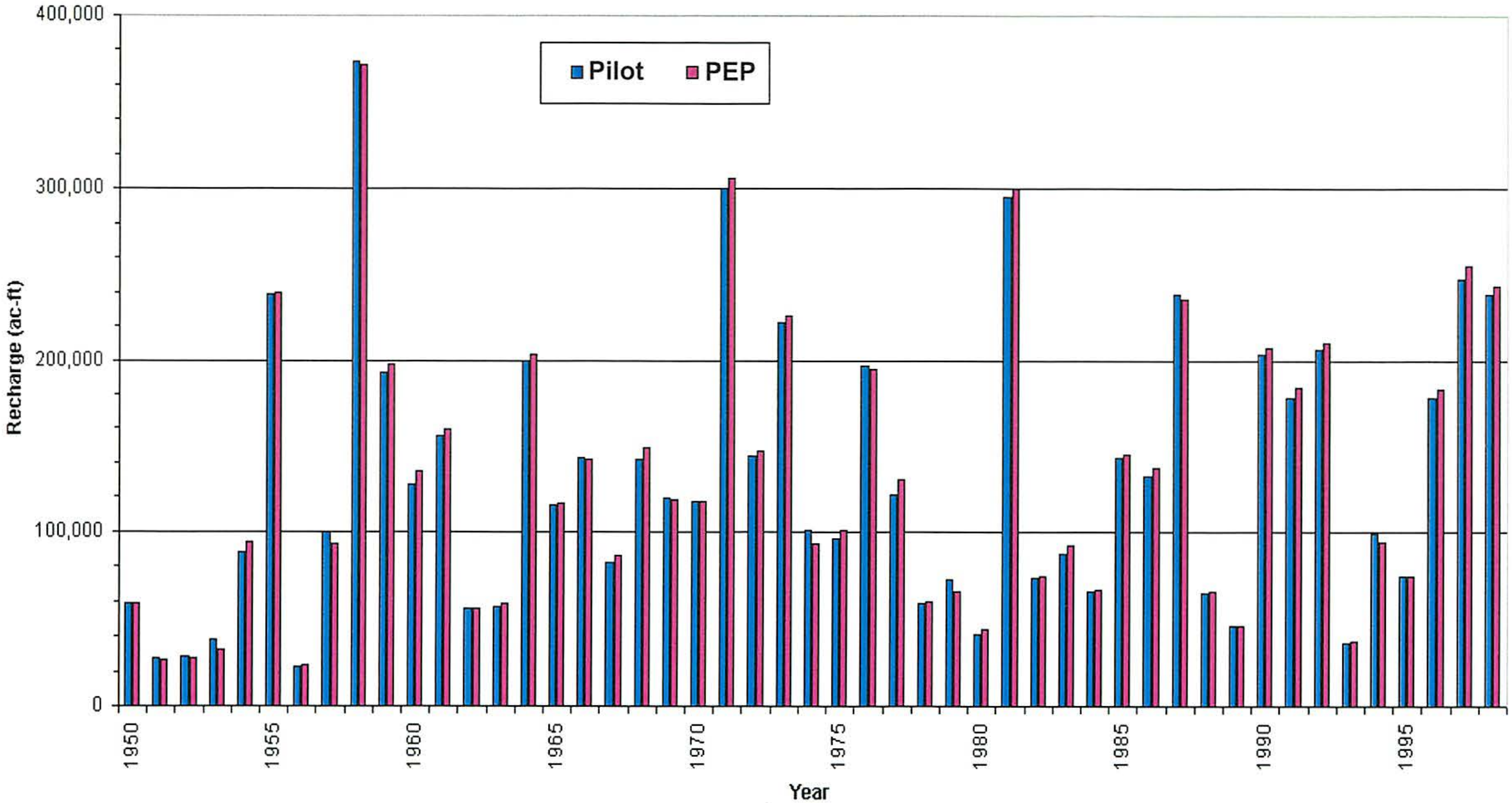
Monthly Streamflow and Diversions for 1993 in Nueces Basin **FIGURE 7**



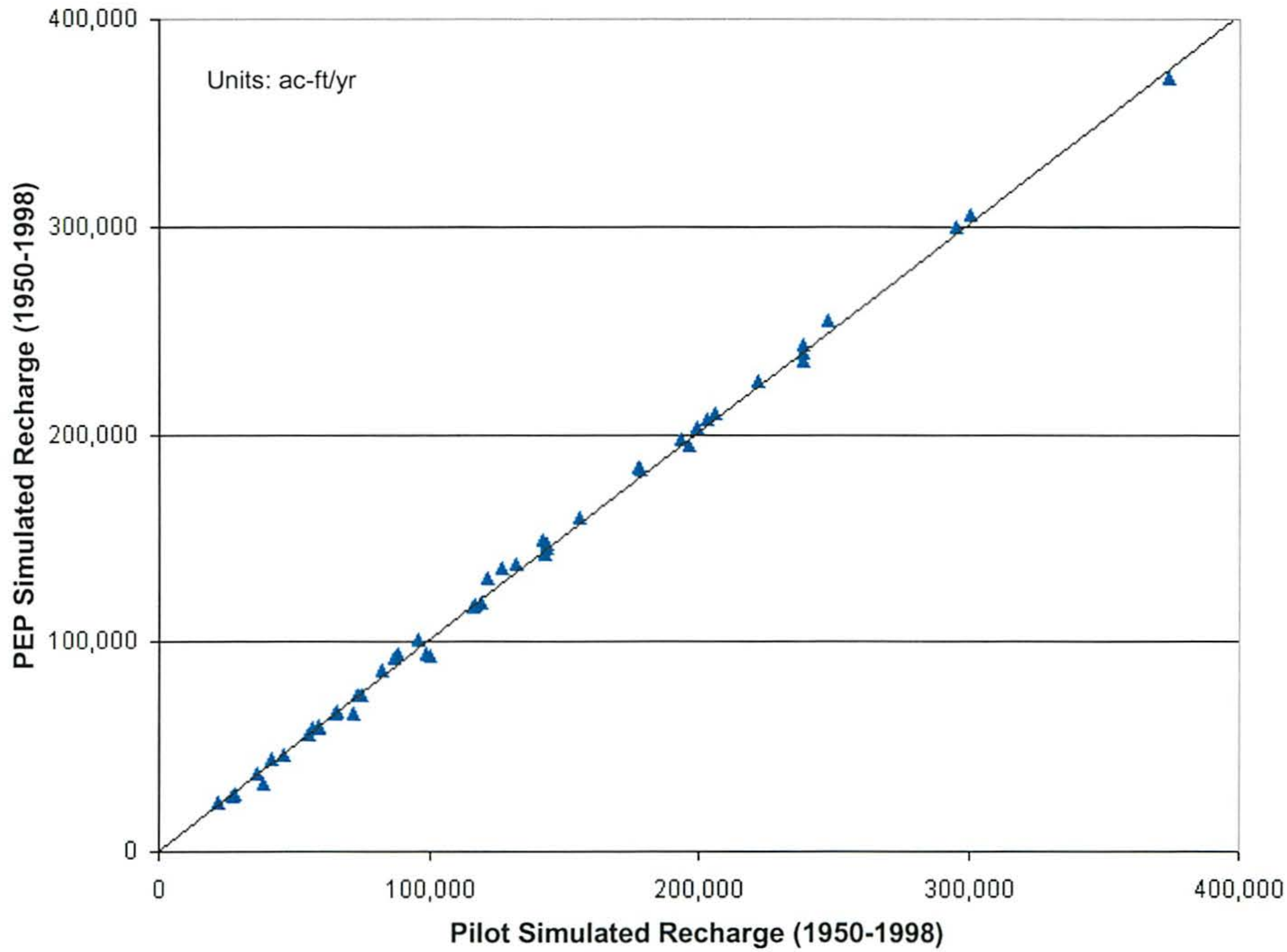
Monthly Streamflow and Diversions for 1994 in Nueces Basin **FIGURE 8**



Monthly Diversions in Nueces Basin **FIGURE 9**

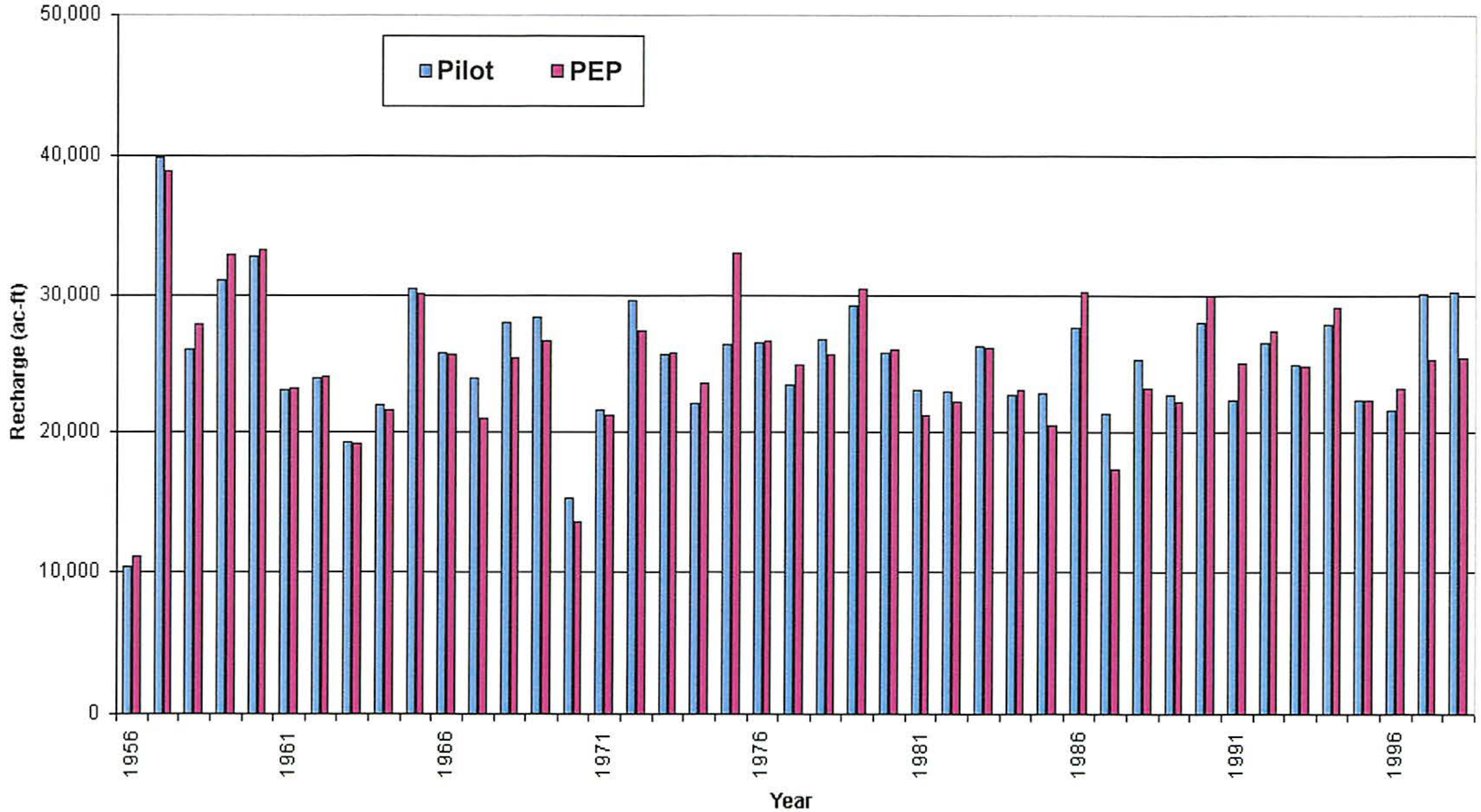


Simulated Recharge for Pilot and PEP Methodology in the Nueces Basin **FIGURE 10**



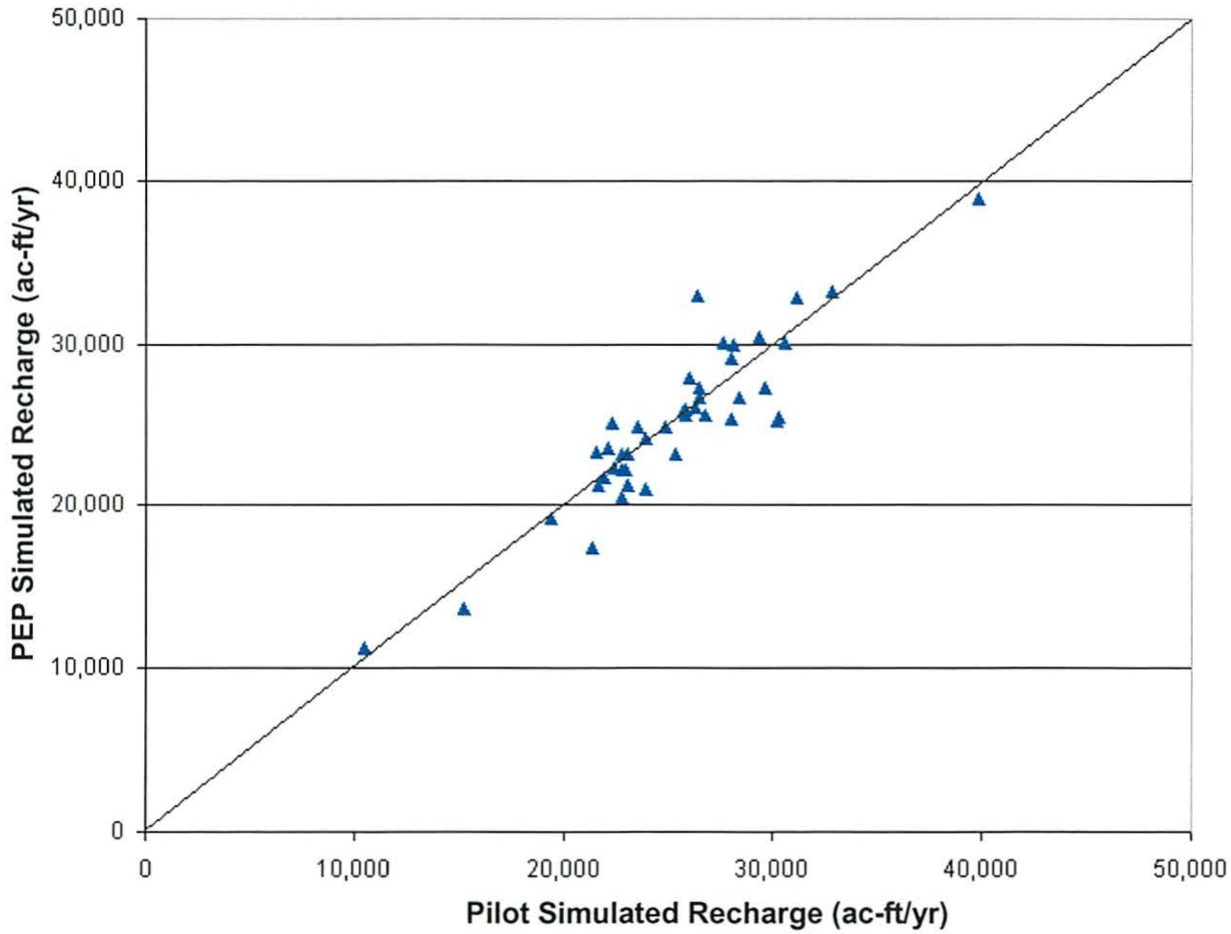
Comparison of Simulated Recharge for Pilot and PEP Methodology in the Nueces Basin

FIGURE 11



Simulated Recharge for Pilot and PEP Methodology in the Blanco Basin

FIGURE 12



Comparison of Simulated Recharge for Pilot and PEP Methodology in the Blanco Basin

FIGURE 13

of the original (pilot) results and the PEP results for the Blanco basin. Although the recharge estimates are typically much smaller for the Blanco basin, Figures 12 and 13 also indicate that the recharge estimates from the different approaches yield very similar results. The comparison of streamflow for the basins is also very good. Both the simulated recharge and the streamflow indicate that there is not a bias in the predictions. In other words, neither model consistently underpredicts or overpredicts streamflow or recharge, but instead, there are small random differences in the results from the approaches due to the small difference in the precipitation data. This finding indicates that the PEP methodology is sufficient for the objectives of this study.

4. Simulation of Enhanced Precipitation

4.1 Simulation of PEP in 1999, 2000, and 2001

Two simulations were completed in each basin to determine the impact of PEP on aquifer recharge. One simulation incorporated the non-enhanced precipitation shown in Table 2 while the second simulation incorporated the enhanced precipitation estimates shown in Table 2. The difference in recharge from the two simulations was then calculated.

Table 3 presents the results of the four simulations by calendar year in terms of total simulated recharge to aquifer in each basin, the increased volume of recharge from the PEP, and the percentage increase in recharge from PEP.

Modeling results indicate the total increased aquifer recharge during 1999, 2000, and 2001 in the Nueces basin was 663, 655 and 654 acre-feet per year respectively, which represents a 0.45, 0.34 and 0.19 percent per year increase respectively. The total increased recharge during the three-year period was 1,972 acre-feet, or 0.29 percent in the Nueces basin. Only half of the Nueces basin is in the cloud seeding zone, which may have reduced the impact of the PEP with regard to aquifer recharge in that basin.

In the Blanco basin, the increased aquifer recharge was 152, 179, and 1,001 acre-feet per year respectively, which represents a 0.44, 0.56 and 1.92 percent per year increase respectively for the Blanco basin. The total increased aquifer recharge during the three-year period was 1,332 acre-feet, or 1.13 percent in the Blanco basin.

The percentage increase in recharge from the PEP was calculated as a percent of the total recharge for the calendar year and would be larger if calculated for the seeding period only. Most of the increased recharge in the Nueces basin was a result of the increased streamflow from the contributing zone, while most of the increased recharge in the Blanco basin was due to diffuse infiltration in interstream areas.

Table 3. Simulated Recharge from Seeded Increments during 1999, 2000, and 2001

Year	Non-Enhanced Recharge (ac-ft)	Enhanced Recharge (ac-ft)	Increased Recharge Volume from PEP (ac-ft)	Percent Increase in Recharge from PEP
Nueces Basin				
1999	146,900	147,563	663	0.45
2000	194,871	195,526	655	0.34
2001	335,713	336,367	654	0.19
3-Year Total	677,484	679,456	1,972	0.29
Blanco Basin				
1999	34,091	34,243	152	0.44
2000	31,826	32,005	179	0.56
2001	51,276	52,277	1,001	1.92
3-Year Total	117,193	118,525	1,332	1.13

4.2 Simulation of Scenario 1 in 1999, 2000, and 2001

According to WWC (2002), the enhanced precipitation during the 1999, 2000, and 2001 seasons could have been increased if more cloud seeding had been performed. To simulate the effect of potentially greater enhanced precipitation, Scenario 1 was developed. Scenario 1 was identical to the simulations described in Section 4.1, except Scenario 1 assumed that the enhanced precipitation was equal to one inch on each of the days listed in Table 2 (i.e., five days for Nueces basin and 8 days for Blanco basin). However, because the increased rainfall was only hypothetical, the impact of increased streamflow due to increased precipitation in the contributing zone was not included in the analysis because the pilot models do not simulate that impact. This means that the results of these simulations show only a portion of the increased recharge that would occur from Scenario 1 precipitation. The results of the simulation are summarized in Table 4.

Table 4. Simulated Recharge from Scenario 1

Year	Increased Recharge Volume from Scenario 1 (ac-ft)	Percent Increase in Recharge from Scenario 1
Nueces Basin		
1999	4,123	2.8
2000	754	0.4
2001	2,029	0.6
3-Year Total	6,906	1.0
Blanco Basin		
1999	1,717	5.0
2000	550	1.7
2001	2,828	5.5
3-Year Total	5,095	4.2

Scenario 1 modeling results indicate that the total increased aquifer recharge during 1999, 2000, and 2001 in the Nueces basin was 4,123, 754, and 2,029 acre-feet per year respectively, which represents a 2.8, 0.4, and 0.6 percent per year increase respectively in the total recharge for the Nueces basin. The total increased recharge during the three-year period was 6,906 acre-feet, or 1.0 percent in the Nueces basin.

In the Blanco basin, the increased aquifer recharge for Scenario 1 was 1,717, 550, and 2,828 acre-feet per year respectively, which represents a 5.0, 1.7, and 5.5 percent per year increase respectively in the total recharge for the Blanco basin. The total increased aquifer recharge during the three-year period was 5,095 acre-feet, or 4.2 percent in the Blanco basin.

Scenario 1 indicates that successful cloud seeding events (on the specific days selected by the PEP contractor) would lead to increased recharge. Although Scenario 1 is hypothetical in that it does not consider if cloud seeding could have increased the precipitation by one inch on the seeded days, the results do indicate that more recharge would have been realized during the 1999, 2000, and 2001 PEP seasons if more enhanced precipitation could have been produced.

4.3 Limitations of Current Modeling Methodology

The existing pilot models for the Nueces and Blanco basins do not simulate the hydrology of the contributing zone above the recharge zone. Rather, these models use the measured streamflow from the USGS gages to determine flow in the rivers at the upstream side of the recharge zone. This approach works very well for estimating recharge to the aquifer based on historical conditions. However, the approach has limitations for the simulations performed in this study because the portion of the measured streamflow at the upstream gage that was contributed by the enhanced precipitation must be estimated. In this study, a simple assumption was used to estimate the increase in streamflow due to cloud seeding. However, it is probable that this simple method is not appropriate for all conditions. In some situations, the increased streamflow from enhanced precipitation in the contributing zone could significantly impact recharge to the aquifer. This is especially true during periods when the streamflow at the upstream gage (i.e., flow originating in the contributing zone) is relatively small prior to a successful cloud seeding event. Under these conditions, the enhanced precipitation and potential runoff from the cloud seeding could result in significantly higher recharge as compared to natural or unseeded runoff.

In this study, there was no information available concerning the spatial distribution of enhanced precipitation resulting from the successful cloud seeding events, thus it was not possible to directly estimate what portion of the enhanced precipitation resulted in streamflow increases at the upstream gages. Therefore, observed streamflow data on the day of (and several days after) the successful cloud seeding event were modified using a very simple method. The most appropriate way to estimate the impact of cloud seeding in the contributing zone is to simulate the hydrology in the entire contributing zone. The amount of increased recharge will depend on several factors, including streamflow conditions prior to cloud seeding and hydrologic conditions (soil moisture, vegetation conditions, etc.) in the contributing and recharge zones.

5. Conclusions and Recommendations

The simulation results indicate that there was an increase in recharge to the aquifer for each basin during the 1999, 2000, and 2001 PEP seasons. The percentage increase in recharge was relatively low in the Nueces basin, partly because there were only five successful cloud seeding events. In addition, only half of the Nueces basin is in the cloud seeding zone, which may have reduced the impact of the PEP with regard to aquifer recharge in that basin. The percentage increase in recharge was higher in the Blanco basin, partly because there were more days when cloud seeding was effective, and the entire basin is located in the cloud seeding region. The Nueces model indicates that most of the increased recharge is from increased channel losses and the Blanco model indicates that most of the increased recharge is from increased infiltration in interstream areas.

A simulation was completed to evaluate the effect of potentially greater enhanced precipitation. The simulation assumed that the enhanced precipitation was equal to one inch on each of the days for which cloud seeding was considered successful (i.e., five days for the Nueces basin and 8 days for the Blanco basin). Results indicated that more successful cloud seeding events (events yielding more enhanced rainfall) would have resulted in more recharge than was realized during the 1999, 2000, and 2001 PEP seasons.

Technical recommendations from this study include:

- Maintain precipitation gage network. These data are critical for verifying and adjusting rainfall estimates from current radar technology.
- Develop watershed models that simulate the hydrology of contributing zone as well as the recharge zone. These models will provide more flexibility in assessing PEP and other water resource programs.
- From the standpoint of increasing aquifer recharge, it may helpful to "optimize" the cloud seeding (PEP schedule) in an effort to enhance precipitation during times when increased runoff would maximize aquifer recharge. Obviously, the optimum times to seed clouds (from a meteorological perspective) may not coincide with the optimum time from an aquifer recharge perspective. Therefore, all of the potential costs, benefits, and risks should be considered simultaneously to address the overall objectives of the PEP. The HSPF recharge models could be helpful for determining optimum conditions for cloud seeding from a hydrologic perspective (i.e., maximizing aquifer recharge, increasing soil moisture, and increasing streamflow, etc.).

6. References

HDR Engineering, 2002. Pilot Recharge Models of the Nueces and Blanco River Basins. Contractor Report prepare for Edwards Aquifer Authority.

Woodley Weather Consultants, 2002. Rainfall Data Summary And Assimilation. Final Report submitted to Edwards Aquifer Authority.