No. 105, ORIGINAL

In The

Supreme Court of the United States

October Term, 1985

STATE OF KANSAS,

Plaintiff,

v.

STATE OF COLORADO,

Defendant,

and

UNITED STATES OF AMERICA,

Defendant-Intervenor.

ARTHUR L. LITTLEWORTH, Special Master

REPORT

VOLUME II

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SECTION XIV

THE 1980 OPERATING PLAN

Colorado has acknowledged that wells drilled east of the Buffalo Canal headgate after 1965 depleted Stateline flows. For example, in its Closing Brief re Kansas' Well Claim Colorado states:

> "Colorado does not dispute that wells drilled east of the Buffalo Canal headgate after 1965 depleted Stateline flows to some extent during the 1970s." At 19; see also RT Vol. 114 at 116; RT Vol. 77 at 23-26; RT Vol. 66 at 47.

However, Colorado maintains that Kansas received substantial benefits from the 1980 Operating Plan; that these benefits have offset the impact of the wells drilled downstream from the Buffalo Canal after 1965; and that adoption of the plan by the authorized representatives of the two states "should bar any claim by Kansas for breach of compact after 1980." Colo. Closing Well Br. at 49-50; RT Vol. 81 at 156; RT Vol. 115 at 67-68; RT Vol. 133 at 70-74. In a later brief, Colorado said that acceptance of the 1980 plan "should bar any claim against Colorado related to postcompact well development in Colorado or the WWSP since 1980." Colo. Response Br. at 27. A more limited contention was presented during oral argument on the Draft Report.

Kansas responds that there are a number of reasons why the Colorado arguments should fail, "but one of these is fully sufficient." Kan. Answer Br. at 13. Kansas refers to Section VI of the 1980 Operating Plan which reads:

> "Adoption of this resolution [approving the 1980 Operating Plan] does not prejudice the ability of Kansas or of any Colorado ditch to object or to otherwise represent its interest in present or future cases or controversies before the Administration or in a court of competent jurisdiction." Jt. Exh. 21, Doc. 11.

While acknowledging the benefits of the 1980 plan, and while allowing the plan to continue in operation, Kansas nonetheless has taken the position from the outset of the case that the plan constitutes an administrative rewriting of Article V of the compact, and thus "is *ultra vires* and legally void *ab initio*." Kan. Pretrial Statement at 165-66. The same position is maintained in Kansas' Reply Brief at 17, 22. It may be that Kansas is merely wary of the 1980 plan being used to establish an accord and satisfaction, which indeed is an affirmative defense alleged by Colorado – although it is difficult to conceive of an agreement subject to a one-year termination clause as an accord and satisfaction. Put another way, this may be a defense reserved by Kansas if Section VI of the plan should prove not to be sufficient, and if the Court were otherwise to bar relief based upon the benefits of the plan.

In any event, during the trial Kansas did not seek to have the plan invalidated; no such claim is included in the pleadings; and Colorado states that it is unnecessary to resolve the issue of the plan's legality in this case. Colo. Closing Well Br. at 57. I agree. The plan clearly represents a more efficient method of operation of John Martin Reservoir, and is beneficial to both states. There is no reason or need here to consider invalidating it.

A. Operation Under the 1980 Operating Plan.

The 1980 Operating Plan has been briefly discussed earlier in Section V of this Report. Duane D. Helton, a primary expert witness for Colorado, was one of the persons mainly responsible for drafting the plan. Colo. Exh. 17 at 81, 86-87. During the 1970s, Helton was an engineering assistant to the Director of the Colorado Water Conservation Board, the official state member on the compact administration. During many of the administration meetings, Helton represented the Colorado Board. He was also chairman of the special engineering committee that evaluated various water use proposals that came before the compact administration, including the winter water program in Pueblo Reservoir. RT Vol. 115 at 64. Involved in the plan negotiations for Kansas were Howard Corrigan, Carl Bentrup, Guy Gibson, and Fred Stoeckley. RT Vol. 81 at 141. Bentrup testified during his deposition that the 1980 Operating Plan was "the most constructive thing" done while he was a member of the compact administration. Colo. Exh. 17 at 91-92. John Martin Reservoir is still operated pursuant to the plan, as slightly revised in 1984. Jt. Exh. 21, Doc. 29.

Briefly, the 1980 plan divides the water conserved in John Martin Reservoir into separate, individual accounts. Kansas is allocated 40% of the conservation storage, with the remaining 60% being divided in specified percentages among the nine canal companies in Colorado Water District 67. Section II-D(2),(3). Kansas and the various Colorado ditches may demand the release of water contained in their respective accounts at any time, and at whatever rates they desire. Helton testified that a storage account system had been talked about for years as a way to achieve "greater efficiency" and beneficial use. RT Vol. 81 at 129-130.

The plan also gives three Colorado canal companies, namely, Amity Mutual Irrigation Company, Fort Lyon Canal, and Las Animas Consolidated Canal Company, additional storage rights in John Martin Reservoir. Amity is permitted to store water which it otherwise could divert from the Arkansas River and store in the Great Plains Reservoir System. The other two canal companies may store water approved under the Pueblo winter storage plan, subject to a 20,000 acre-feet limit for Fort Lyon, and a 5,000 acre-feet limit for Las Animas. Of the water thus stored by these three Colorado canal companies 35% now goes into a Kansas transit loss account. Releases of stored water from the Kansas account are measured at the Stateline, and transit losses between John Martin Reservoir and the Stateline are made up from this Kansas transit loss account. Section III-D, Section II-E(4).

Under the 1980 plan, all winter flows are stored in John Martin Reservoir, and Colorado gives up its right to demand releases of 100 cfs during the winter season. Kansas also waives its compact right to divert summer river flows between 500 and 750 cfs. Summer inflow goes to the Colorado users in District 67 unless such flow exceeds their existing irrigation requirements by at least 1000 acre-feet. Under those circumstances, summer flow goes into conservation storage to be allocated among the various accounts.

B. Benefits Under the 1980 Operating Plan.

Evidence was introduced during the trial in an effort to quantify the benefits to Kansas under the plan, and to compare such amounts with estimated depletions. In the post-trial briefs, there is also considerable argument about which state benefitted more from the changed method of operating John Martin Reservoir. But I do not believe that such evidence and argument are useful, considering the way in which I have analyzed the issues raised by Colorado. The fact is that both states received significant benefits, and both states yielded certain rights otherwise available under the compact. RT Vol. 81 at 155-56; RT Vol. 66 at 54-55.

For Kansas, the 1980 plan guaranteed that it would receive 40% of the water stored in the conservation pool, and it allowed Kansas to call for water more nearly in accord with its crop demands. Under the common pool concept provided in the compact, to receive its fully allowable share, Kansas had to call for water whenever Colorado did, whether or not Kansas farmers then needed the water. There is evidence that in the early years Kansas did not always do so, and thus received less than 40%.

The 35% charge on water stored in John Martin by the three Colorado canal companies and the use of this water to establish a transit loss account also solved a long-standing and troublesome problem. Kansas' share of the river has always been determined at John Martin Reservoir, but measured in equivalent flow at the Stateline some 58 miles downstream. Transit losses have long been a problem. Colo. Exh. 21 at 133, 136-37; Colo. Exh. 17 at 55-59, 82. As a result of all of these changes, Colorado maintains that Kansas has received a larger percentage of water from John Martin Reservoir, and an increase in usable flows at the Stateline. Colo. Reply Br. at 5.

For Colorado, storage of water in their offstream reservoirs was most inefficient. A USGS paper indicates that only about half of the water diverted into storage entered the distribution system. Colo. Exh. 94 at 1. Helton described the Great Plains Reservoir System as "very inefficient." RT Vol. 81 at 125. By allowing Amity to store its Great Plains water in John Martin Reservoir, Bentrup testified that Amity "stood to gain a substantial windfall." Colo. Exh. 17 at 83. In fact, however, the savings were shared approximately equally with Kansas. Although the charge of 35% on stored water was a negotiated figure, the basis for that percentage lay in sharing the water gained by storing water in John Martin instead of in the Great Plains System. RT Vol. 81 at 136-37. In addition, each of the nine canal companies received its own separate account and no longer had to compete for released water, being able to call for it when most needed. Colorado users also received 24/35 (69%) of any excess waters left each year in the Kansas transit loss account. Fort Lyon and Las Animas were also permitted to store water from the Winter Water Storage Program in John Martin.

It is undisputed that the 1980 plan was beneficial to the water users in both states. Helton so testified, as did other witnesses. RT Vol. 81 at 155-56; RT Vol. 33 at 50-51, 104; Colo. Exh. 17 at 91-92. The 1980 plan was negotiated and evolved through several test years beginning in 1976 when Amity was first permitted to store in John Martin Reservoir. Jt. Exh. 21, Docs. 3, 4, 5, 7, 8, 9, 11. The negotiations were thorough, between parties of equal stature, with give and take by both states, and with several different approaches being taken during the test years.

C. Intent of the 1980 Operating Plan.

I do not find support for the Colorado argument that the benefits to Kansas under the 1980 plan should offset Stateline depletions caused by well pumping in Colorado. The plan itself indicates that it was intended to improve the efficiency of the operation of John Martin Reservoir. The recitals state that the then present operation of the conservation features of the reservoir did not result "in the most efficient utilization possible of the water under its control"; and the recitals include an administration finding that the plan may "result in more efficient utilization of water." There is nothing in the plan itself to indicate that it was intended to be used as an offset against compact violations, or as a solution to the impact of well pumping in Colorado.

I have also reviewed the record, specifically the numerous documents included in Joint Exhibit 21 that led to the development of the 1980 plan. These negotiations and various interim arrangements began in 1976, but there is nothing in the evidence that reflects the fact that the plan was intended to offset the impact of well pumping, or was a settlement of Kansas' well claims.

In its Closing Brief re Kansas' Well Claim, Colorado maintains that the 1980 plan was a practical solution devised "to address changes in the regime of the Arkansas River brought about by well development in both States." Page 19. In its Reply Brief at page 5, Colorado reiterates that the 1980 plan was a "fair and equitable solution to the problems caused by increased well development in both States." *Id.* at 22. However, Colorado provides no evidentiary citations to support these statements, nor do I find that this was the intent of the plan.

Kansas argues that the Colorado position would override Article IV-D of the compact, essentially allowing an administrative modification of the compact without the required consent of Congress. Colorado responds that the 1980 Operating Plan comes well within the authority of the Arkansas River Compact Administration under the compact; that Colorado does not contend that the compact can be lawfully altered without the consent of Congress; and that the issue is only whether Kansas' conduct may be considered in the attempted enforcement of an equitable right or remedy. However, these arguments go beyond what needs to be decided here since I do not believe there was any intent that accepting benefits under the 1980 plan would preclude any future well claim under the compact.

Colorado also states that both states realized that "the only feasible method to develop the unused waters of the Arkansas River below John Martin Dam was through additional well development." Colo. Closing Well Br. at 22. Colorado cites testimony by Helton to support this argument, but I believe its brief overstates his testimony. Helton expressed only his own belief, not what "both States realized," adding, however, "that is what both States did," namely, to allow well development. RT Vol. 86 at 78-79; RT Vol. 115 at 64.

During oral argument on my Draft Report, Colorado presented a more limited argument with regard to the 1980 Operating Plan. No longer did it assert that approval of the Plan should bar *any* claim for well depletions after 1980, but rather that it "should mitigate damages to Kansas for the period after 1980." RT Vol. 143 at 41-43. In support of this position, Colorado placed heavy emphasis on the deposition of Carl Bentrup, a longtime Kansas representative to the Arkansas River Compact Administration. It is asserted that Bentrup believed that transit losses of water released from John Martin Reservoir were due at least in part to well pumping, and that his testimony "clearly establishes that the 1980 Operating Plan was intended to mitigate the impact of well pumping in Colorado." Colo. Oral Argument Memorandum at 46, 48.

There is no doubt that in the dry years of 1977 and 1978 transit losses between John Martin and the Stateline were a concern, but the evidence indicates that the problem lay primarily with surface diversions by the Colorado ditches, not with wells. Kansas' compact entitlement from John Martin Reservoir is to be "satisfied by an equivalent in Stateline flow." Article V-E(3). In Bentrup's view, if Kansas' water was not reaching the Stateline, the only way to rectify the situation was to "curtail Colorado ditches." Colo. Exh. 17 at 59. Indeed, Colorado's compliance efforts were directed at such surface diversions, not at well pumping.

In 1977 the ditch companies below John Martin by mutual agreement stored winter water in the reservoir, and voluntarily allowed conservation pool releases in the spring to run past their respective headgates for the first 24 hours. Kan. Exh. 462. In 1978 the Colorado Water Commissioner of Water District 67 issued an order to the same effect, but Amity Mutual then refused to comply. With the support of the compact administration, the Colorado State Engineer sought an injunction against Amity, but the water court dismissed his complaint. *Id.* The water court concluded that acting against only the ditch companies within District 67 was discriminatory; moreover, that prior action by the compact administration was required. Without ruling on these issues, the judgment of dismissal was affirmed on appeal. *People ex rel Danielson v. Amity Mutual Irrigation Co.*, 668 P.2d 1368 (Colo. 1983).

The 1980 Operating Plan was intended, in part, to deal with these transit loss problems, but the evidence does not support the view that it was also intended to mitigate compact violations from well pumping. Nor was any such claim made by Colorado when Kansas formally complained to the Arkansas River Compact Administration in 1985 about well pumping in Colorado.

D. Conclusions.

The 1980 Operating Plan provided benefits to both Kansas and Colorado which were separately bargained for. There is no evidence to support the claim that the benefits to Kansas were in settlement of its well claims. Colorado received ample consideration under the agreement for the 1980 plan without a waiver of Kansas' well claims. The benefits received by Kansas under the plan should not be offset against compact violations, and should not be a bar to any of the Kansas claims in this case.

Colorado also states that Kansas should be barred from claiming that it is entitled to an accounting based upon demands for releases from John Martin Reservoir which are different from those called for under the plan. Colo. Closing Well Br. at 57. Once conservation storage has been released to Kansas in accordance with the plan, Colorado states that the remedy available to Kansas is limited to terminating the plan. Colo. Response Br. at 25-26. I am not aware that Kansas takes a contrary view of either of these statements. So long as the 1980 plan is not terminated or determined to be invalid, it is controlling on the releases from John Martin Reservoir.

SECTION XV

PRECOMPACT PUMPING ALLOWANCE

Both Kansas and Colorado acknowledge that some wells were in existence during the precompact years, and that pumping of groundwater did occur. Both states also agree that a certain amount of pumping should thus be allowable under the compact. However, the states are in major disagreement over the extent of this allowance. In fact, in terms of potential impact on Stateline flows, the amount of so-called "precompact" pumping is the largest quantitative issue in the case.

Kansas estimated that groundwater pumping in 1948 between Pueblo and the Stateline amounted to approximately 11,000 acre-feet. Kansas considers this to be the amount of pumping thus "grandfathered" under the compact and allowable in postcompact years. Over the 1950-85 period, Kansas estimated that total pumping by Colorado users amounted to 5,810,000 acre-feet. Kan. Exh. 731. Of this total, Kansas considered that 396,000 acre-feet (i.e., 11,000 acre-feet per year) represented allowable pumping under the compact. *Id.* Thus, in attempting to estimate impacts on Stateline flows resulting from postcompact pumping, the Kansas H-I model used the difference, namely 5,414,000 acre-feet over the 1950-85 period, as the measure of the alleged wrongful pumping. *Id.*

In contrast, Colorado estimated pumping for each of the years from 1940 through 1949 with annual amounts that varied from a high of 36,837 acre-feet to a low of 14,891 acre-feet. Colo. Exh. 165*, Table 9.8. However, in determining allowable pumping under the compact, Colorado did not use the amount of water actually produced, but rather relied upon the claimed right of precompact wells to pump. Colorado determined which wells had precompact dates of appropriation, and for each post-compact year Colorado calculated allowable pumping by using a ratio based upon the decreed acreage of the precompact wells divided by the decreed acreage of all wells for each given year. Colo. Closing Well Br. at 63. Using this methodology, Colorado's calculation of allowable pumping by precompact wells averaged 49,275 acre-feet per year over the 1950-85 period, or a total of 1,774,000 acre-feet. Colo. Exh. 692 b*; Kan. Exh. 731. Colorado estimated total pumping by all wells for the 1950-85 period at 5,227,000 acre-feet. Subtracting the claimed allowance for precompact wells, the amount of pumping which Colorado used to determine Stateline impacts was 3,453,000 acre-feet for the 1950-85 period. *Id.* This would compare with the Kansas figure of 5,414,000 acre-feet.

At stake, therefore, is whether or not 1,378,000 acre-feet of postcompact pumping or some portion thereof will be considered as allowable under the compact. This amount is the difference between Kansas' allowance for precompact pumping of 396,000 acre-feet and Colorado's claim of 1,774,000 acre-feet for precompact wells. *Id.* Colorado's expert witness Dewayne Schroeder called this the major reason for the different estimates of Stateline depletions. RT Vol. 139 at 109.

A. Estimated Amounts of Actual Precompact Pumping.

Kansas estimated that more than 800 wells were in existence in 1948. One of its exhibits shows 849 wells, while its post-trial brief puts the number at approximately 880. Kan. Exh. 30, Table 2; Kan. Opening Br. at 11. The Colorado estimate for 1949 is 717 wells. Colo. Exh. 165*, Table A.1. Although Dr. Danielson testified that "numerous wells" existed in precompact times, he said they "weren't relied upon generally," and that reliance on wells was "not substantial." RT Vol. 76 at 35. This situation did not change until the "severe" drought in the 1950s and the corresponding development of the high capacity turbine pump and the availability of cheap energy. *Id*; Jt. Exh. 157 at 8.

By today's standards, the wells of 1940-48 appear fairly primitive. Dr. Danielson described them:

> "The Witness: Generally speaking, your Honor – and we have Mr. Longenbaugh who is a pump expert – but my experience is they were centrifugal pumps operated usually with electric motors, but oftentimes with a tractor backed up with a 90 degree gear head on it or something or large pits dug with the pump set down close enough to the water table that they could get a decent suction and then operated sometimes with a prime mover up on top or a power line up on top and huge belts running down into the pit. Generally speaking, centrifugal pumps of some sort. That isn't to say that there weren't any turbine pumps. I think there probably were, but the pumping was primarily by centrifugal lift pumps.

> Special Master: So the turbine pumps were developed primarily in the late 40's, early '50's?
>
> The Witness: At least that is where the major application began. The technology, I'm sure, was there prior, but the application would be really in that dry period in the '50's when the big surge in well development came." RT. Vol. 76 at 102.[62]

According to Danielson, these old centrifugals were generally replaced with the more efficient turbine pumps. RT Vol. 76 at 105.

Prior to the trial of this case, pumping for 1940-49 had been estimated in five separate hydrologic reports. None of these reports, however, estimated amounts that approached the yearly average of 25,228 acre-feet submitted by Colorado for use in the trial. Calculated from Colo. Exh. 165*, Table 9.8. The first of these earlier studies was the 1968 Wheeler Report prepared pursuant to Colorado legislation. The yearly average in that report was 10,600 acre-feet, ranging from 2300 in 1940 to 23,000 in 1949. Jt. Exh. 92 at 22. Then in 1970 the USGS issued the results of an intensive study that included similar figures, estimating 1940 at about 2000 acre-feet and increasing to 23,000 at the end of the decade. Jt. Exh. 66; Colo. Exh. 993.

In 1975 the Colorado state engineer's office published another report done under the supervision of Dr.

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62 Helton also agreed that the older wells in existence in the 1930s and 1940s "were pretty inefficient, just big holes," and modern day wells didn't come into being until after World War II with the development of the turbine pump and cheap electricity. RT Vol. 82 at 136-37.

Danielson who was then the deputy state engineer. Jt. Exh. 94. This report was introduced into evidence on behalf of the state engineer during the trial of *Kuiper v. Atchison, Topeka & Santa Fe Ry. Co.*, and in support of his amended rules and regulations on pumping. (See Section XI(I) herein.) The report appears to have relied upon the USGS 1970 work, estimating the 1940-50 average at 12,600 acre-feet per year. Jt. Exh. 94 at 49. However, during this trial, Danielson testified that the annual pumpage figures in the report do not now seem to be reasonable, although he offered no corrections. RT Vol. 78 at 83-84.

In 1985 the USGS issued another report in which it repeated the pumping estimates published in its 1970 report. Jt. Exh. 129 at 10. Finally, in 1986, the United States Department of Agriculture in participation with the Colorado Water Conservation Board issued a report on the Arkansas River Basin which again included the early pumping estimates found in the 1970 USGS Report. Jt. Exh. 108 at I-11, A-15.

Determining the general level of precompact pumping is important if that is to be the measure of allowable pumping under the compact. It should be noted, however, that Colorado objects as a matter of law to the use of a single value for this purpose. Nonetheless, I find that 15,000 acre-feet per year is the most reasonable figure to represent pumping in precompact years. This is the highest amount estimated in each of the five reports for the years during which compact negotiations took place. Experts for both states also relied heavily on data from the 1970 USGS report (Basic-Data Release No. 21) in which this 15,000 acre-feet estimate appears. Moreover, Colorado called one of the authors of the Report as a witness and he staunchly defended the accuracy of the USGS's pumping estimates. RT Vol. 129 at 61-62, 64. This was Thomas J. Major, a USGS employee from 1959 to 1985.

The Colorado Supreme Court stated that in 1940 only 2000 acre-feet were being pumped from wells in the Arkansas Valley. *Fellhauer v. People*, 167 Colo. 320, 447 P.2d 986 at 991 (1968). This 2000 acre-feet amount is in contrast to the figure of 36,837 calculated by Colorado for this trial. Colorado also used the USGS data (Basic-Data Release No. 21) in its 1975 report prepared for proceedings before the Water Court, and introduced into evidence. RT Vol. 76 at 88, 94; RT Vol. 77 at 35-36; Kan. Exh. 514 Vol. 1 at 5, 49-53, 145-52, 211-14. And from the Kansas viewpoint, its expert testified that while he thought 15,000 acre-feet was high, it was nonetheless reasonable. RT Vol. 125 at 60-61, 69.

Counsel for Colorado in his cross-examination of Kansas expert Dale E. Book did expose some inconsistencies in Joint Exhibit 94 which includes the 1940-49 pumping estimates published by the USGS in Basic-Data Release No. 21. The cross-examination concerned Table 7 in Joint Exhibit 94 which was prepared by the Colorado state engineer's office. It purports to show not only the total amount of water pumped for each year from 1940 through 1972, but also the amount of electric power associated with the pumping for each such year. The table states that the power data is taken from USGS Basic Data Release No. 21. However, those data do not appear in the USGS report, and no one seemed to know where they came from. RT Vol. 126 at 58; RT Vol. 130 at 49. Book agreed, however, that the relationship between the power data and water consumption did not appear to be reasonable for some years. RT Vol. 126 at 58. Hal Simpson, the Colorado state engineer, was of the same opinion. RT Vol. 130 at 51. In comparing certain years, power consumption decreased while pumping increased.

However, the evidence is without dispute that the published power records for this early period were incomplete, and it may well be that it is the power data on Table 7 not the pumping estimates that are inaccurate. Virtually nothing is known about these power figures, but the pumpage estimates have been accepted, published and used by the State of Colorado, the courts, the U.S. Department of Agriculture, and the USGS, and in the case of USGS as late as 1985. Moreover, there is persuasive testimony by one of the authors of the Basic-Data Release No. 21 (where the pumping estimates but not the power consumption figures appear) as to the accuracy of that USGS publication.

As an alternate to this 15,000 acre-feet figure, Kansas estimated 1948 pumping to be approximately 11,000 acre-feet. Colorado argues that this figure is both unreasonable factually and wrong as a matter of law. Colo. Closing Well Br. at 60, 66. The year 1948 was wet, and I believe that Kansas' use of this single year is subject to the legitimate criticism that diversions were likely to have been high and pumping low. RT Vol. 82 at 133, 139; RT Vol. 84 at 17; RT Vol. 111 at 118, 120. The 15,000 acre-feet figure more likely reflects the general amount of Colorado's pumping that was affecting the flows of the Arkansas River at the time of the compact negotiations.

Colorado also developed pumping estimates for the 1940-49 period for use in this trial. Its annual average was 25,228 acre-feet, but I have some concern about these higher numbers. During oral argument on my Draft Report, Colorado sought an even larger amount, on the order of 36,000 acre-feet annually. Both states relied upon power consumption records as the basis for calculating pumping. However, because the early data were incomplete, Book testified that something over half of Colorado's estimated power usage during the precompact years came not from actual data but through regression analyses. RT Vol. 125 at 57. For 1940-45 these analyses depended upon a single data point taken from the Pueblo office of CENTEL, and the amounts of Las Animas energy were correlated to SECPA values which themselves had been estimated. RT Vol. 71 at 56-60, 91. Colorado's pumping figures also included adjustments for pumping by nonelectric wells, and for pump efficiencies.

In making these adjustments, Colorado extrapolated backward in time from the 1964-68 well data collected by the USGS and published in Basic-Data Release No. 21. RT Vol. 125 at 49. As a result, Colorado assumed that nonelectric pumping increased going back in time as a percentage of total pumping. RT Vol. 126 at 56. Moreover, its analysis assumed that the older pumps in the 1940s were more efficient, and hence pumped larger quantities of water for any given amount of power consumption. RT Vol. 72 at 6-7; RT Vol. 125 at 58; RT Vol. 126 at 36-37, 43. However, it appears that the Colorado analysis did not take into account the replacement of centrifugal pumps with the more efficient turbine pumps that occurred in the late 1940s and early 1950s.

For whatever reason, the result of the Colorado approach is to make pumping in 1940 the highest amount in the whole decade of the 1940s.[63] This result seems questionable in light of all the earlier studies showing increasing pumping throughout the 1940s, and the new wells which continued to be drilled throughout the decade. Colorado's own report puts the number of additional wells drilled between 1941 and 1949 at 122. Jt. Exh. 94 at 19. A lower rather than higher estimate of early 1940s pumping is also supported by the fact that during the compact negotiations the engineering committee made no effort to include pumping as part of the diversion data, or indeed at all. Jt. Exh. 5 at 3. The historic division of flow between the two states was considered on the basis of surface diversions alone.

B. Colorado's Theory of the Entitlement of Precompact Wells.

While Colorado did introduce protective evidence on the amounts of precompact pumping, Colorado rejects the idea of using any single value to represent the amount of pumping that is allowable under the compact. Instead, Colorado argues that postcompact pumping by precompact wells will vary from year to year depending upon the crops grown, hydrologic conditions, and the amount of surface water available. Colo. Closing Well Br. at 62. Precompact wells, according to Colorado, should be allowed to pump in the later years the amount of water

[63] It is generally acknowledged that 1940 was a very dry year. Jt. Exh. 5, Tables 1-7; RT Vol. 126 at 67.

needed to supply "unmet demand" and permitted under Colorado law. RT Vol. 114 at 30, 32. Such unmet demand was based on sufficient water for optimum crop production. RT Vol. 70 at 40. In order to quantify such amounts, Mr. Helton testified to a "decreed acreage" approach which was based upon his understanding of the entitlement of these wells under Colorado law. Colo. Reply Br. at 31.

Colorado first identified the wells with precompact dates of appropriation. These were considered to be wells that existed on May 31, 1949. RT Vol. 84 at 20. It should be noted that such appropriation dates were not decreed until sometime after 1969. It was not until the 1969 legislation in Colorado that all wells were required to be registered, and a procedure was established to determine retroactively the appropriation dates based upon the dates when the wells began to pump, and also to determine the acreage irrigated.[64] The precompact amount of decreed acreage in the Colorado analysis is thus a fixed figure. RT Vol. 82 at 139. It is 43,724 acres. RT Vol. 83 at 7.

In each year in the 1950-85 period, Helton testified that Colorado's experts then determined the total amount of pumping, and the total amount of decreed acreage associated with such pumping. Next, Colorado calculated a ratio for each year based on the decreed acreage of the

[64] These were largely uncontested proceedings, and Colorado acknowledges that not all of the data may have been accurate. Colo. Response Br. at 72. However, it is not necessary to consider this issue further since I conclude that Colorado's reliance on these decrees to establish the amount of pumping allowed under the compact was not proper as a matter of law.

precompact wells divided by the total decreed acreage of all wells, and applied that fraction to the total amount of pumping for the year. RT Vol. 82 at 139; RT Vol. 84 at 14-16. In Helton's opinion this decreed acreage approach was the best way to estimate the volume of water pumped that was associated with precompact wells. RT Vol. 84 at 16. While the amount of such pumping varied year by year, the annual average for 1950-85 was 49,275 acre-feet. RT Vol. 82 at 136; RT Vol. 133 at 54; Colo. Exh. 135* at 1.1. This compares with average postcompact pumping by all wells of 145,199 acre-feet per year, as estimated by Colorado. Since 1976, the total decreed acreage for such wells has been in the order of 171,000 acres. Colo. Exh. 165*, Table A.1. In analyzing the impact of postcompact pumping on Stateline flows, Colorado then used the difference between these pumping amounts (49,275 and 145,199 on average), namely, an average of 95,925 acre-feet per year. Colo. Exh. 135* at 1.1. Of course, the impact was actually determined on an annual basis, and those amounts were then totalled.

Colorado's legal rationale for this approach is based first on Article VI-A(2) of the compact. It reads:

> "(2) Except as otherwise provided, nothing in this Compact shall be construed as supplanting the administration by Colorado of the rights of appropriators of waters of the Arkansas River in said State as decreed to said appropriators by the courts of Colorado, nor as interfering with the distribution among said appropriators by Colorado, nor as curtailing the diversion and use for irrigation and other beneficial purposes in Colorado of the waters of the Arkansas River."

Moreover, Colorado argues:

> "Article IV-D of the Arkansas River Compact imposed limits on future development and construction in both States, but not on existing development. The Kansas Commissioners who negotiated the Compact undoubtedly understood that pumping by wells in Colorado with precompact dates of appropriation would vary from year to year for the same reasons that diversions by surface ditches vary from year to year. They also undoubtedly understood that wells which were drilled before the Compact was approved, but became fully operational after the date of the adoption of the Compact would relate back to the date of the appropriation, because that had long been Colorado law." Colo. Response Br. at 71.

I believe there are several fallacies in Colorado's theory. I disagree with the Colorado argument that the rights of the precompact well appropriators, as decreed by the Colorado courts, are "binding on Kansas." Colo. Response Br. at 73. See *Hinderlider v. La Plata River & Cherry Creek Ditch Co.*, 304 U.S. 92, 102, 82 L.Ed. 1202, 58 S.Ct. 803 (1938); *Texas v. New Mexico*, 462 U.S. 554, 564, 77 L.Ed.2d 1, 103 S.Ct. 2558 (1983); *Frontier Ditch Co. v. Southeastern Colorado Water Conservancy District*, 761 P.2d 1117, 1123-24 (Colo. 1988). First, Article VI-A(2) does not render Kansas' Stateline entitlement subordinate to whatever appropriative rights may be decreed by Colorado courts. The Article begins with the phrase, "Except as otherwise provided," and must be read in conjunction with Article IV-D. I conclude that Article VI-A(2) was not meant to override the obligations of Colorado under Article IV-D. The compact was intended, *inter alia*, to maintain in the future the general allocation of the natural river flows between the states that had existed in precompact years. Article IV-D was the primary means of accomplishing this result by preventing additional depletions. It applies not only to new construction but also precludes the "improved or prolonged functioning of existing works" if such development would cause a material depletion of usable Stateline flows. I find that new wells, the replacement of centrifugal with turbine pumps, and increased pumping from precompact wells all come within this provision. The compact negotiators did not intend to permit water use in either state to be increased at the expense of the other.

Second, it should be noted that the compact specifically provides that the ditch diversion rights within Colorado Water District 67 and in Kansas between the Stateline and Garden City shall not be "increased beyond the total present rights of said ditches" unless the compact administration finds that such increase would not result in a material depletion of usable flows. Article V-H. At the time the compact was negotiated, Colorado had no system for establishing the "rights" of wells. However, I cannot believe that the compact was intended to limit increased surface diversion rights, but to allow new rights to be later established for wells that would change the river allocation between the states.

Third, I disagree with Colorado about what the Kansas commissioners who negotiated the compact "undoubtedly understood." Indeed, I do not believe that any of the commissioners, either from Colorado or Kansas, had in mind the development of the deep turbine pump or the possibility of such a dramatic increase in pumping. The controlling factor here is the language of the compact and the intent of the compact negotiators, a fact that Colorado acknowledges. Colo. Response Br. at 71, fn. 18. Pumping at the time was so insignificant that it did not even enter the discussions. But the relative allocation of water between the states, based on usage over recent times, did lie at the heart of the negotiations. The compact was intended to protect and maintain that general allocation – and to divide the new benefits of John Martin Reservoir storage. The Colorado legal theory and evidentiary approach would upset that allocation by some 1.7 million acre-feet over the 1950-85 period. I conclude that no such result was intended.

Following the issuance of my Draft Report, Colorado argued that if a single figure is to be used to represent precompact pumping, then the USGS estimate of 15,000 acre-feet is too low. Colorado asked that the amount of allowable precompact pumping be reconsidered. Colorado maintained: (1) that the 15,000 acre-feet amount was limited to pumping from the valley-fill aquifer only, and did not include pumping from the surficial aquifer; (2) that it also omitted irrigation wells with a capacity of less than 100 gpm; (3) and, finally, that climatic conditions during the precompact years were wetter than in later years, with the result that precompact pumping was less than normal. For this reason Colorado sought an upward pumping adjustment of 15 percent.

Colorado argued that including pumping from the surficial aquifer would increase the estimate by 5,180 acre-feet.[65] Adding wells under 100 gpm involved another 6.1 percent, according to Colorado, bringing the total to 21,400 acre-feet of pumping in 1948. Colo. Oral Argument Memorandum at 25. These adjustments alone would increase the total amount of "grandfathered" pumping by 238,000 acre-feet. However, in Colorado's view these figures were still low. Based on the calculations of its experts,[66] Colorado argued that the precompact pumping figure should be "at least 31,500 acre-feet." *Id.* at 26-27. When adjusted by 15 percent for climatic conditions, the full Colorado claim comes to just over 36,000 acre-feet. *Id.*

The first issue is whether the 15,000 acre-feet figure omitted pumping from the surficial aquifer. Counsel for Colorado stated that the "great bulk" of the surficial wells were located in the Bessemer service area, and it was "absolutely clear" that the area was excluded from the USGS 1964-68 study area. RT Vol. 143 at 17, 39. It does, indeed, appear that the intensive field work carried

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[65] This amount is based on 29.1 acre-feet per well for 178 wells, that is, the number of wells shown in the Colorado data base for 1948. Colo. Oral Argument Memorandum at 24. The 29.1 acre-feet number is the result of dividing 515 wells in the valley-fill aquifer into 15,000 acre-feet. Colorado's calculations assume that production from the surficial aquifer is at the same rate as from the valley-fill, although the evidence generally was to the contrary. See, e.g., Colo. Exh. 165*, Tables A.2, A.3.

[66] Colorado's experts estimated that during the 1940s large-capacity irrigation wells produced on average 41.3 acre-feet. This amount was multiplied by 717 wells, taken from Colorado's well data base in 1949, and then increased by 6.1 percent to include wells under 100 gpm. Colo. Oral Argument Memorandum at 26-27.

on by the USGS in 1964-68 was limited to irrigation wells of 100 gpm or more located in the valley-fill aquifer. That is what the text of the report states, and Kansas has not disputed the study area for those years. Jt. Exh. 66 at 1, 10 (Table 2); Kan. Supplemental Comments at 13. But that is not to say that the pumping estimates for the earlier years, namely 1940-63, were collected for the same area. Nor is the USGS study (Joint Exhibit 66) the only report that must be considered.

In 1968 the Wheeler Report, done at the request of the Colorado legislature, was published. Pumping estimates in the Wheeler Report for the 1940s are close, but not identical, to the USGS figures for the same period of time. Jt. Exh. 92 at 22; Jt. Exh. 94, Table 7 at 22. Pumping in 1940, according to Wheeler, was put at 2,300 acre-feet; increasing to 15,000 acre-feet during the years (1946-48) when the compact was being negotiated; and averaging 10,600 acre-feet for the 1940-49 period. *Id.* Significantly, however, the Wheeler Report *does* include the wells located on the Bessemer Terrace, that is, in the surficial aquifer. Jt. Exh. 92 at A-10. For the Bessemer Canal, the Wheeler Report lists 301 wells in the Bessemer Terrace and 47 in the alluvium. Moreover, the well data for 1940-65 was said to have been obtained from the Colorado Water Conservation District, based on maps plotted from the USGS study. *Id.* at 22-23.

No one is sure how the pumping estimates before 1963 were reached. RT Vol. 133 at 49. Yet it is clear that the only power records available for that period were based on utility service areas. Colo. Exh. 165*, Table 2.1. There were no distinctions in the power records between electricity supplied to wells located in the valley fill aquifer and those in the surficial aquifer. Nor do later reports referring to or incorporating the USGS early pumping estimates indicate that they were limited to the valley fill aquifer.[67]

In short, I find that the evidence does not support the Colorado claim that pumping from the surficial aquifer was omitted from the precompact estimates, requiring an increase in the 15,000 acre-feet figure used in this Report.

Nor am I persuaded that the precompact pumping estimate should be increased to account for small-capacity irrigation wells, or for climatic conditions. Colorado's claim for a 6.1 percent increase for small capacity wells is based on the argument that for 1964-68 the Kansas pumping estimates exceeded those of the USGS by 6.1 percent. Colo. Oral Argument Memorandum at 24-25. Admittedly, the Kansas figures included wells of 50 gpm capacity, while for those years the USGS inventoried only wells of 100 gpm or more. But there is no evidence that the difference in pumping estimates can be attributed to the differences in well capacities. Indeed, for all but one of the years *before* 1964, the Kansas pumping estimates prepared for this trial were less than the USGS figures. Colo.

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[67] Jt. Exh. 92 at 22 refers to 1940-65 pumping from the "Arkansas Valley." Jt. Exh. 94 speaks of wells "tapping the alluvium of the Arkansas River Valley," and lists wells "Drilled Annually – Arkansas River," (1940-72) at 17, 19. The 1985 USGS Report incorporates the earlier BDR 21 data as estimates of pumping "ground water in the Arkansas Valley," and refers to problems caused by withdrawals "from alluvial aquifers." Jt. Exh. 129 at 9.

Exh. 993. Nor did I adopt the Kansas estimates to establish a precompact pumping allowance.

With respect to any climate adjustment, it certainly is true that pumping may vary depending upon the weather and the amount of river flow available for surface diversions. However, the conclusion that precompact pumping, except for some wet years, would have been 15 percent greater is highly speculative.

Finally, Colorado attempted during oral argument on the Draft Report to justify a higher precompact pumping allowance by making various comparisons of the amounts of water pumped per well. This effort included comparisons with precompact wells in Kansas, and also a comparison of the average pumping per well in Colorado as calculated by Kansas for the 1950s and 1960s. However, the foundation is simply insufficient to make meaningful comparisons of this kind. Arithmetical averages alone are not useful without evidence to analyze the shift from centrifugal to vertical turbine pumps, without considering the changing distribution between electric and nonelectric wells, and without knowing the different geologic conditions that affect well productivity.

There is no precise answer to the amount of precompact pumping, or even as to the particular years that should be considered in making a compact allowance. That amount must simply remain as an estimate of water use that affected the general allocation of water between the states when the compact was being negotiated. Two responsible reports, one published by the USGS and one prepared for the Colorado legislature, reached similar conclusions as to the amounts of Colorado pumping during the 1940s. These reports were done much closer to the time period involved, and without the pressure of trial advocacy. They have since been used by the Colorado State Engineer. I have relied on these reports and recommend that the highest annual amount shown to have been pumped during the negotiations, namely 15,000 acre-feet, should be allowed under the compact.

SECTION XVI

POSTCOMPACT PUMPING IN COLORADO

Establishing the total amount of water pumped by wells along the Arkansas River during the postcompact years is one of the major issues in the case. It is not a matter easily resolved. Colorado generally does not require meters on wells, and has had no comprehensive system calling for reports of the amounts of water pumped. RT Vol. 65 at 78-79; RT Vol. 67 at 114-16. Colorado State Engineer Simpson did testify, however, that he is now requiring the two major well organizations in the Arkansas River Valley to measure power coefficients and to estimate pumping based on power records. RT Vol. 130 at 52-53. The Water Court decrees establishing appropriative rights for wells do so in terms of a rate of flow (cfs), and do not limit the quantity of water that may be pumped, although the permitted acreage may be restricted. RT Vol. 65 at 75. It was necessary, therefore, for both states to develop their own pumping estimates for the postcompact period, that is, from 1950 to 1985.

Pumping estimates are sometimes made through the consumptive-use method, which is based upon crop demand, irrigation efficiency, effective precipitation, and surface water supply. However, these variables are not commonly measured or known with much accuracy. Another recognized method, which in fact was used in this case, is based upon energy consumption. This system requires data on the amount of energy supplied to the well, and the development of a "power coefficient."[68] This factor is the amount of power required to pump a unit volume of water. Estimates from this methodology can be quite reliable if the basic data are complete. However, as might be expected in any effort to reconstruct pumping as far back as 1950, problems exist with the data. The efforts made by the experts for both states were indeed commendable, and their results differed by only about 10%.[69] However, that percentage difference still amounts to a considerable amount of water over the full postcompact period.

A. Kansas' Estimate of Pumping.

Kansas estimates that pumping along the Arkansas River in Colorado between Pueblo and the Stateline, over the 1950-85 period, amounted to 5,810,000 acre-feet. Kan. Exh. 731.[70] This amount includes wells located in both the valley fill and bench aquifers. It is limited to irrigation wells, and does not include municipal or industrial pumping. Average annual pumping over the 36-year

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[68] Sometimes described also as the "power consumption coefficient," or "power conversion factor," or "energy consumption factor."

[69] Dale E. Book of Spronk Water Engineers, Inc. did the work for Kansas. Colorado used Boyle Engineering Corporation, and James E. Slattery was the principal author of Boyle's report on pumping. Colo. Exh. 165*.

[70] In an earlier exhibit, Kansas originally estimated total pumping at 5,934,370 acre-feet. Kan. Exh. 32. However, the 5.81 million acre-feet (MAF) figure is the amount used by Kansas in its revised H-I model.

postcompact period amounted to 161,394 acre-feet. Kan. Exhs. 689, 731.

B. Colorado's Estimate of Pumping.

Colorado's estimate of total pumping over the 1950-85 period is 5,227,000 acre-feet. Kan. Exh. 731. The annual average is 145,200. Colo. Exh. 852. Colorado's estimate was also limited to irrigation wells, but only for those located in the greater of the ditch service areas or the valley fill aquifer. Colo. Exh. 165* at 1. The difference between the total pumping estimates of the two states over the 1950-85 period is 580,000 acre-feet.

C. Estimates of the Number of Wells.

The states also differ on the number of wells. Kansas inventoried wells with a capacity of more than 50 gallons per minute (gpm), and found that the total number of such wells in Colorado in 1985 was 2,543. Colo. Exh. 851. Colorado, on the other hand, used 100 gpm as its criterion for an irrigation well in order to coincide with the definition used by the USGS in its Basic-Data Release No. 21 (BDR No. 21). Jt. Exh. 66. Colorado's total for number of wells was 2057. Colo. Exh. 851. This total by Colorado represents permitted and decreed wells, which is not necessarily the same as the number of active wells located physically on the ground. RT Vol. 129 at 41-42. Finally, Kansas included wells located in the bench aquifers as well as those in the valley fill, while Colorado confined its analysis to a more limited "mainstem" area.

The difference, however, in the total number of wells reported by the two states is not significant for the purpose of estimating total pumping. Colorado prepared a comprehensive comparison of the wells located in the valley fill aquifer, which is where most of the wells are located. The comparison was limited to wells of 100 gpm or more. Colo. Exhs. 403a*-c*, 788; RT Vol. 68 at 63. Using this common basis, Colorado concluded that Kansas listed 137 wells that Colorado did not include, and that Colorado listed 93 wells not shown by Kansas. Colo. Exh. 788. The net difference was 44 wells, with a total of 1717 wells being identified by Kansas and 1673 by Colorado. Book agreed that this exhibit was correct. RT Vol. 125 at 35.

Simpson testified there were roughly 50 more alluvial wells under 100 gpm that could be added to the difference. RT Vol. 68 at 66. However, Colorado did not believe that these smaller wells were significant. At most a well of such size can irrigate only 4 or 5 acres. RT Vol. 68 at 73. According to the Colorado analysis, which appears to be carefully done and reliable, Colorado's slightly smaller number of wells is due primarily to the following factors: a Colorado field survey that found that certain wells listed by Kansas were not in fact used; the fact that some of the Kansas wells were duplicated in its computations; and the fact that Kansas included some old wells constructed before 1957 which had never been adjudicated. Colorado in its inventory assumed that these unadjudicated wells had been abandoned or were not in use. RT Vol. 68 at 66-67. On the other hand, Colorado listed 81 adjudicated wells that Kansas did not show. RT Vol. 68 at 71. In short, the difference in the total number of wells is not as large as it first appears, but of more importance, both Book and Slattery agreed that the difference is not significant considering how the data were used. RT Vol. 125 at 36; RT Vol. 70 at 59-60.

D. Common Methodology Used by the States.

Both states generally use the same methodology in order to estimate total pumping. The first step is to assemble the records of electric power consumed for irrigation purposes in the Arkansas River Valley. A number of utilities supplied such power: Southeast Colorado Power Association (SECPA), Southern Colorado Power Company (CENTEL), Lamar Light and Power, Las Animas Municipal Light and Power, the Town of Holly. Records of the Colorado Public Utilities Commission were examined, and Colorado also utilized records from Colorado State University. Power used to supply "lift pumps" is subtracted from these data. A lift pump is not used to extract water from a well, but typically is a "ditch pump" lifting water from a canal to a higher elevation.

Two of these power companies, SECPA and CENTEL, also served electricity for irrigation purposes outside of the Arkansas River Valley. It was necessary therefore to segregate from total energy deliveries the amount of power used by wells along the Arkansas River within the respective study areas of the states. The distribution of SECPA power is in substantial dispute. Both states then applied power coefficients, or power conversion factors, to translate kilowatt hours into acre-feet pumped. For this purpose, both states relied upon power coefficients developed by the USGS during its 1964-68 study, BDR No. 21.

Jt. Exh. 66. In that study the USGS identified 1348 large irrigation wells (over 100 gpm) located in the valley fill aquifer. Data on well location, depth of well, depth to water, discharge rate, and the power source (electricity or gas) were collected for most of these wells. In addition, spring and fall water level measurements were taken over the 1964-68 period, and the electric and gas meters on the wells were read at the same time. *Id.* at 2, 4.

A power coefficient is dependent upon a number of factors, including pump and motor efficiency, well head discharge pressure, and the pump lift (number of feet between the groundwater level and the surface of the ground). Both states made adjustments to the power coefficients for changes over time in the groundwater levels, but only Colorado made a further adjustment for pump efficiencies. RT Vol. 69 at 70-71, 115, 122.

Lastly, both states made adjustments for pumping by nonelectric wells. There were no records available of fuel used, such as natural gas, to drive the pumps on nonelectric wells. However, in its 1964-68 study the USGS did inventory the nonelectric wells. This inventory is considered to be reliable for the 1964-68 period. Colo. Exh. 165* at 12.

In comparing the pumping estimates of the two states, the most significant differences result from: the allocation of Southeast Colorado Power Association energy to the study area along the Arkansas River; the adjustments made by Colorado to the power coefficients for pump efficiencies; and the amounts of extractions assigned to nonelectric pumping. Each of these differences is now discussed.

E. The Allocation of Southeast Colorado Power Association (SECPA) Energy.

In the SECPA service area, computerized section-by-section records were available for the period 1977-1985. These data were used by the experts for both states to allocate power to their respective study areas, and the resulting pumping estimates during this period were quite similar. The differences arise during the years 1950-76. During this period of time, the opposing methods of allocation of SECPA energy to the mainstem area account for an average pumping difference of 12,474 acre-feet per year. Colo. Exh. 822 at 2. Spread over the entire 1950-85 period, Colorado attributes an average of 9356 acre-feet per year of the total pumping difference to the SECPA issue. Colo. Exh. 822, Table 1.0.

Complete ledger billing sheets from SECPA were available for the years 1953-60 and 1973-74, but were incomplete during the intervening years. These ledger sheets contained the data used for customer billing, including meter readings and the locations of meters. Kan. Exh. 627. For the years when the ledger sheets were complete, Kansas relied upon them directly to make the necessary allocation of SECPA energy. For the 1961-72 period, when complete ledger sheets were not available, Kansas estimated the portion of total irrigation energy supplied to the mainstem area based on percentages of the total power for the periods prior and subsequent to 1961-72. Colo. Exh. 660 at 5.

Colorado agrees that these ledger sheets, if they could be accurately interpreted, "would provide a better basis to allocate power in the SECPA service area to the mainstem area than the percentages used by Mr. Slattery," Colorado's expert. Colo. Response Br. at 81. However, Colorado maintains that the ledger sheets required too much interpretation to be reliable, and therefore used none of them. RT Vol. 70 at 17; RT Vol. 72 at 109-13. Instead, Colorado allocated SECPA energy for 1968-77 essentially on the basis of a straight line interpolation between the values used by the USGS in its 1964-68 study and SECPA's computerized records that became available in 1977. In the years before 1964 for which it did not have records, Colorado relied upon correlations that it developed with other electric suppliers. Power records generally were incomplete for the 1940-60 period, and missing records were estimated using regression techniques. Colo. Exh. 165* at 3. Because of the deficiencies in its power data, Colorado's expert testified that his pumping estimates for the years prior to 1960 had a range of uncertainty of "probably about plus or minus 20 percent." RT Vol. 69 at 94.

The dispute over allocating SECPA energy resulted in very large differences in the annual pumping estimates from 1971 through 1976, ranging from 21,163 acre-feet to 60,247 acre-feet. Colo. Exh. 822, Table 1.0. In each instance the Colorado estimate was lower. The largest difference of 60,247 acre-feet occurs in 1974 when complete ledger sheets were available and were used by Kansas but not by Colorado. The SECPA issue largely turns on a question of whether these ledger sheets were more reliable than the interpolations and correlations utilized by Colorado.

Colorado's expert Slattery testified that use of the ledger sheets involved "a great deal of interpretation" and the possibility of error made them an unreliable source of data. RT Vol. 71 at 139; RT Vol. 70 at 17. Slattery also added, however, that the ledger sheets were not used because of "the level of effort of digitizing that large of a data base." RT Vol. 70 at 17. Kansas had offered one of the ledger sheets in evidence as an example. Kan. Exh. 627. Slattery acknowledged that this particular sample was simple to read, but said that it was an exception. RT Vol. 72 at 30, 103, 113. Slattery then produced another ledger sheet that he claimed was more difficult to read and would be more typical of the type that was generally available. Colo. Exh. 811; RT Vol. 72 at 113. Slattery testified that this example was subject to a series of different interpretations, and was "very confusing" to him. RT Vol. 72 at 110.

With the acquiescence of counsel, I called Kansas' expert witness Book back to the stand, without warning, to see if he could read this ledger sheet. RT Vol. 72 at 114. Book showed no hesitation, and had no difficulty in extracting all of the pertinent information from the ledger sheet. RT Vol. 72 at 133-41. Interpretation of the sheets, he acknowledged, required care but posed no problem. RT Vol. 72 at 137.

For the years 1957 and 1958 the amount of energy allocated to the mainstem area by Kansas on the basis of summing up all of the ledger sheets slightly exceeded the total amount of power reported to have been supplied by SECPA. RT Vol. 70 at 12; Colo. Exh. 660, Table 1A. The reported total company production came from records filed with Colorado State University, under a voluntary program. RT Vol. 62 at 40-41; RT Vol. 72 at 38-39. Colorado cites this inconsistency as another reason why the ledger sheets could not be used reliably. Colo. Response Br. at 81-82. Indeed, because of these two years Slattery concluded that the ledger sheets overestimated power for all the years. This argument assumes, however, that the Colorado State University records for those two years were more accurate than Kansas' interpretation of the ledger sheets. There was no evidence establishing the accuracy or completeness of the reports filed with the university, while we do know that the ledger sheets were used to bill customers for the amounts of power shown.

In the years 1973 and 1974, which were far more important to the pumping estimates than 1957-58, Kansas' summation of the ledger sheets allocated 75% and 74%, respectively, of the company's total power sales to the mainstem area. Colo. Response Br. at 82. These percentages compare favorably to Slattery's testimony that over all the years about 80% of the SECPA energy was delivered to the mainstem area. RT Vol. 72 at 96. In contrast, the Colorado allocation to the mainstem area for 1974 was only 44%. RT Vol. 72 at 49.

Colorado relies heavily on the USGS 1964-68 study. Jt. Exh. 66. One of the authors of that study testified that the USGS also used individual ledger sheets obtained from the power companies, that he considered them to be as accurate as any information one could get, and that they were "very clear," not difficult to read or understand. RT Vol. 129 at 26, 36.

I find that the ledger sheets provide the best source of data available for allocating the amount of SECPA energy delivered to the study area along the Arkansas River, and that such data can be reliably used. I find further that Kansas' allocation of SECPA energy, based upon the use of the ledger sheets, provides the most reliable estimate of power supplied to the study area, and should be used in determining the amount of pumping in that area.

F. Pumping from Nonelectric Wells.

While the large majority of pumps in the Arkansas Valley have been operated with electrical energy, a considerable amount of water has also been produced using nonelectric pumps, that is, pumps driven by natural gas, diesel or gasoline fuels. The differences between the states in estimating the amount of such nonelectric pumping average 4511 acre-feet annually over the 1950-85 period. Colo. Exh. 822 at 3. Kansas' estimate is higher considering the whole postcompact period, although in the earlier years Colorado estimated higher amounts of nonelectric pumping. Virtually no data are available on the amounts of energy supplied to nonelectric wells over the 1950-85 period.

The only comprehensive study of nonelectric wells was made by the USGS as part of its 1964-68 investigation. The USGS not only inventoried the various kinds of nonelectric wells, but also assembled data from which pumping estimates from these wells could be made. Of 1342 active wells for which the power source was reported, the USGS found 1136 electric wells and 206 nonelectric wells. Colo. Exh. 165*, Table 7.1. The nonelectric wells were further divided into 62 natural gas wells and 144 diesel or gasoline wells. In all, they comprised about 18% of the wells studied.

Kansas used microfilm data for the year 1968 taken from that USGS study to determine the ratio of electric to nonelectric pumping for 1968. RT Vol. 126 at 48. The Kansas experts then applied that same ratio to later years, but subject to a "cap." The cap actually amounted to 26,900 acre-feet annually, which was the amount of nonelectric pumping calculated by Kansas for 1968. Kan. Exh. 689 at 3. The use of the cap stabilized nonelectric pumping at 26,900 acre-feet for each year from 1971 through 1982. Colo. Exh. 822, Table 4.0. For the years 1983-85, the amount was slightly less. The Kansas approach thus limited any increase in nonelectric pumping during the dry years of the 1970s, but it did not take into account evidence that the number of nonelectric wells decreased over the years.

Colorado, in making its estimates of nonelectric pumping, relied not only upon the 1964-68 USGS data, but also upon several localized studies, and upon the experience of two irrigation experts who had worked in the Arkansas Valley for many years. Two of these localized inventories of nonelectric wells were made in the 1940s. Colo. Exh. 165*, Table 7.1. A more comprehensive inventory was made by the Colorado state engineer in 1985. Of 887 wells included in the 1985 report, 825 were electric and 62 or about 6% were nonelectric (58 natural gas wells and 4 diesel wells). *Id.* In 1991 the Colorado state engineer's office also completed a field investigation of a limited number of wells located downstream from John Martin Reservoir under the Buffalo Canal, and located south of the river in the area served only by wells. RT Vol. 68 at 76-77; RT Vol. 126 at 50. Between 40 and 50 wells were included in this survey.

Within the Buffalo Canal service area 14.5% of the wells were nonelectric, and in the area south of the river the figure was 9.5%. RT Vol. 68 at 76; RT Vol. 126 at 45-46.

Unlike Kansas, Colorado based its estimates of nonelectric pumping upon a declining ratio of nonelectric to electric pumping over time. There is substantial evidence in the record, uncontroverted by Kansas, that the number of nonelectric wells has decreased over time. Besides the several inventories noted above, this conclusion is firmly supported by the testimony of Robert A. Longenbaugh and Donald L. Miles. Mr. Longenbaugh has been employed by the Colorado Division of Water Resources since 1981, and when he testified was an assistant state engineer. Prior to 1981 he was with Colorado State University for 19 years, serving as an Extension Irrigation Specialist and an Associate Professor in civil engineering. He was responsible for maintaining an observation well network of approximately 1200 wells in Colorado, begun by CSU in 1929; he worked on many projects involving irrigation and pump efficiencies along the Arkansas River; and he coauthored a textbook chapter on farm pumps. Kan. Exh. 624.

Until his retirement in 1988, Mr. Miles worked for more than 20 years with the Cooperative Extension Service associated with Colorado State University, and for some 15 years was stationed at Rocky Ford on the Arkansas River. Moreover, he grew up on a farm under the Fort Lyon Canal. He published a wide range of research reports and articles, and worked closely with farmers helping them to make management decisions.

Both Miles and Longenbaugh had years of personal experience as irrigation experts assisting farmers along the Arkansas River.

Longenbaugh and Miles testified that natural gas prices rose significantly in the early 1970s because of the Arab oil embargo. RT Vol. 63 at 199; RT Vol. 65 at 151. Moreover, there were problems with the BTU rating of natural gas, and SECPA seized the moment to launch a heavy promotional effort to get farmers to convert to electricity. RT Vol. 65 at 151-52. As a result, there was a conversion from fossil fuel energy to electricity. Miles testified that at the present time about 97% of the wells valley-wide are electric. *Id.* The percentage would be a little lower downstream of John Martin Reservoir, where the bulk of the nonelectric wells are located. *Id.* Book also acknowledged that both natural gas and diesel prices had increased in the early 1970s, and indeed that some conversion to electricity had occurred. RT Vol. 23 at 107. The increase in the amount of SECPA power sold during this period of time may also suggest a significant conversion to electricity, although to some extent it may reflect increased pumping during the dry years. In 1973 SECPA sales along the Arkansas River were 6.7 million kWh. By 1976 this amount had increased to 18.1 million kWh. RT Vol. 23 at 109.

There is a good deal of uncertainty in the estimates of nonelectric pumping provided by both states. However, I find that the Colorado methodology more accurately accounts for the reduction in the number of nonelectric wells, which I believe did occur. Accordingly, the Kansas estimates for total pumping should be adjusted to reflect the nonelectric pumping estimates calculated by Colorado.

G. Pumping Adjustment for Decline in Well Efficiencies.

There is no dispute over the fact that the efficiencies of both wells and pumping plants generally decline with age unless properly maintained. RT Vol. 23 at 105. Under those circumstances, a given amount of energy may in fact pump less water than when a well is more efficient, or put conversely, it may take more energy to produce the same amount of water. If pumping is to be estimated on the basis of energy supplied and the use of a power coefficient, it may be necessary therefore to adjust that coefficient over time. Colorado made such an adjustment to its pumping estimates. Kansas did not, believing that the facts did not warrant such a change. Colorado's pump efficiency adjustment reduced its estimate of total pumping by an average of 6618 acre feet annually for the period 1950-85. Colo. Exh. 822 at 4.

Colorado relied initially, as did Kansas, on the power coefficients measured by the USGS in its 1964-68 study. Colorado, however, then adjusted those power coefficients on the basis of certain random measurements made in 1981. The 1981 investigation was part of a national program to measure power coefficients, and involved 72 wells along the Arkansas River in Colorado. Kan. Exh. 625; RT Vol. 71 at 131. Colorado expert Slattery acknowledged that this was a relatively small sample of recent power coefficients. RT Vol. 71 at 114. Also, it was not possible to equate the 1981 measurements with values used for specific wells in the 1964-68 study. RT Vol. 69 at 126. Nonetheless, Slattery testified that the decline in pump efficiencies shown by these 1981 measurements corresponded to the opinions of Longenbaugh and Miles. RT Vol. 69 at 125, 127; RT Vol. 72 at 14, 25-26. Accordingly, Slattery developed a declining relationship between the 1964-68 and 1981 measurements, which essentially was on a straight line basis. RT Vol. 69 at 132; RT Vol. 72 at 6.

Kansas received the 1981 data during the discovery period of this case, but Book concluded that such data "did not indicate a sufficient decline in efficiency of the pumping units for 1965 to 1981" to warrant any change. Moreover, he believed that the results were heavily influenced by an "outlier" in the data, and that the Colorado analysis did not appropriately consider pump replacements. RT Vol. 125 at 42. Book assumed that pump replacement "would happen logically through the aging of the pumps and wells in the valley." *Id.*

Book's assumption, however, was vigorously disputed by Longenbaugh. On the basis of his extensive personal experience along the Arkansas River, Longenbaugh testified that efficiencies had decreased considerably over time "because of the wear of the pump and that they [farmers] don't change out the pumps." RT Vol. 63 at 190; RT Vol. 69 at 125; RT Vol. 71 at 116. There was little economic incentive to do so. RT Vol. 63 at 185. Speaking of his efforts in working with farmers to make their irrigation systems more efficient, Longenbaugh testified:

> "It cost more to get the well driller and the pump installer to go and pull the pump and put it back in than what they could save in power bills over a several year period. There was no

> incentive for them to go ahead and do it. I was amazed when I did the numbers and that is what it came out to be." RT Vol. 63 at 185.

Into the 1970s, power was sold at a declining block rate so that the more power a farmer used, the less it cost. RT Vol. 63 at 191. Most farmers did not use their wells every day, and so if additional water was needed, the farmer merely pumped another day. RT Vol. 65 at 70. Miles was also of the opinion that the efficiency of wells in existence during the 1960s had declined. RT Vol. 66 at 31. Additionally, he pointed out that some changes in irrigation systems had adversely impacted pump efficiencies. Farmers used to pump into open ditches, but many systems changed over to underground pipelines, creating an additional head on the pump and requiring more power for the same volume of water. RT Vol. 66 at 27; RT Vol. 63 at 190.

Longenbaugh testified that pump efficiencies during the 1960s were about 45-50%. In the 1980s, in his opinion, those efficiencies had declined to approximately 40-45%. RT Vol. 71 at 127. Miles testified that in his opinion even the latter efficiencies were too high under current conditions. RT Vol. 66 at 25-27. The calculations which Slattery used to adjust the 1964-68 pump efficiencies generally fell within Longenbaugh's range. RT Vol. 72 at 5. Slattery testified that he had relied "very heavily" on Longenbaugh. RT Vol. 71 at 119; RT Vol. 69 at 125.

Slattery acknowledged that he had no actual data on pump replacements, and had used the age of wells as a surrogate for the average age of pumps. RT Vol. 71 at 121. But neither did Kansas have any data on pump replacements. Very few new wells, and few replacement wells, were drilled upstream of John Martin reservoir after 1965. Colo. Exh. 165*, Table A.1; RT Vol. 71 at 115-16. While wells continued to be drilled downstream of John Martin after 1965, the ratio of older to newer wells was still 490 wells in 1965 compared to 90 wells added thereafter through 1985. Colo. Exh. 165*, Table A.1. Longenbaugh thought that ages of the wells gave an indication of average pump age. RT Vol. 71 at 115.

On cross-examination, Kansas raised legitimate questions about the impact of one data point (Bland well) used in the 1981 study, and whether the 1981 measurements, although random, were truly representative. RT Vol. 72 at 9-19; RT Vol. 72 at 106-07. Kansas also uncovered a mistake in one of the power coefficients used by Slattery which had resulted in an underestimation of center pivot pumping from 1971 to 1985 of 300-400 acre-feet annually. RT Vol. 72 at 67, 123-24. Overall, however, Kansas offered no evidence of its own on pump efficiencies after the 1964-68 USGS measurements. Book made no independent investigation to determine how frequently pumps were repaired or replaced. RT Vol. 23 at 106.

The Kansas experts certainly understood that well efficiencies can decline with age, and that the power coefficients on which they relied were some twenty years old. Kansas failed to show that its pumping estimates did not require an adjustment because of declining pump efficiencies. While certainly the data relied upon by Colorado to reach specific acre-feet values were not as complete as might be desired, I find that the 1964-68 power coefficients on average did decline, and that an appropriate adjustment is required. The Colorado evidence is accepted.

H. Conclusions.

I conclude that the best estimate for total postcompact pumping for the 1950-85 period is 5,810,000 acre-feet, less the adjustments submitted by Colorado for declining pump efficiencies (corrected for the center pivot coefficient mistake), and less the adjustments utilizing Colorado's calculations for nonelectric pumping.

SECTION XVII

WELL DEVELOPMENT IN KANSAS

Colorado points to the fact that the large increase in postcompact wells did not occur only in Colorado, and that in western Kansas a comparable if not greater proliferation of new wells also occurred. Colorado argues that new wells increased the irrigated acreage in western Kansas to more than 300,000 acres; that such pumping has caused groundwater levels to decline substantially; that groundwater contributions to the Arkansas River in Kansas have been reduced or eliminated; that increased pumping has caused greater transit losses in the river, depleting the flows available to Kansas ditches; and that until 1978, Kansas took no action to restrict well development in western Kansas. All these facts are basically true, but they do not constitute a defense to Colorado's liability under the compact.

Article IV-D of the Arkansas River Compact protects the "waters of the Arkansas River" against material depletion from future development, which indeed includes development in Kansas as well as Colorado. However, the waters of the river are defined as those originating "upstream from the Stateline." Article III-B. The excessive pumping by Kansas farmers is essentially mining the Ogallala Aquifer. Jt. Exh. 140 at 1. While this may portend serious problems for Kansas in the future, the Ogallala groundwater supply in Kansas is not directly covered by the compact.

A. Irrigated Acreage in Kansas.

At the time the compact was approved, the acreage in Kansas irrigated by surface diversions and wells between the Stateline and Garden City was in the order of 66,000 acres.[71] RT Vol. 36 at 53; Kan. Exh. 348 at 34; RT Vol. 37 at 136-37. The evidence does not permit a breakdown between acreage supplied by alluvial wells and acreage irrigated by nonalluvial wells, if any. A recent study shows that land irrigated from the Arkansas River, that is, by surface diversions and alluvial wells, is about 57,000 acres. Kan. Exh. 358*.

Colorado refers to the acreage irrigated in 1979 in Hamilton, Kearny and Finney Counties, a total of some 351,000 acres. Jt. Exh. 139 at 15; Jt. Exh. 140 at 11; Colo. Closing Well Br. at 25. However, much of this land is outside of the service areas of the Kansas canal companies that divert from the Arkansas River. Most of the new acreage is irrigated by wells drawing from the Ogallala Aquifer, not from the Arkansas River or its alluvium. About 100,000 acres of the new irrigation referred to by Colorado were developed from the mid-1960s through the 1970s in sand hills south of the river. RT Vol. 37 at 24. This area is outside the service area of South Side Ditch, and is irrigated solely by wells using center pivot sprinklers. *Id.* at 24-27. It was the development of the center pivot system that made irrigation in this area possible.

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[71] Kramer's Report to Congress in 1949 uses the figure of approximately 65,000 acres. Jt. Exh. 16 at 37.

In Hamilton County, upstream of the Bear Creek Fault zone, there is no association between the Arkansas River and the Ogallala formation. In that reach, the river alluvium is contained in a trough eroded through bedrock. RT Vol. 29 at 134. Downstream of the fault zone, essentially in Kearny and Finney Counties, the river alluvium is separated from the Ogallala Aquifer by a "major confining zone" which consists of silt, sandy silt and clay. RT Vol. 30 at 47-49. This confining zone, which ranges from near zero to about 200 feet thick, is not an aquifer and does not provide water to wells.[72] *Id.* at 49; Jt. Exh. 140 at 8. While there is some opportunity for the vertical movement of water through the confining zone, the upper alluvial aquifer and the lower Ogallala Aquifer "act independently." RT Vol. 30 at 49, 78. It is common knowledge, of course, that the Ogallala underlies a vast area encompassing parts of several states. There was no evidence that such groundwater came from the waters of the Arkansas River originating in Colorado.

B. Increase in Kansas Wells.

The increase in the number of wells in western Kansas is shown decade by decade in a series of maps introduced by Colorado. Colo. Exhs. 284* through 289*. In 1949 there were about 416 wells in the three-county area from the Stateline to Garden City. Colo. Exh. 257*. This

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[72] The hydraulic conductivity of this zone is "very low," ranging from 1/100 to 1/10,000 of a foot per day. This compares with hydraulic conductivity in the upper alluvial aquifer of 82 to 200 feet per day, and 80 to 150 feet per day in the lower Ogallala Aquifer. RT Vol. 30 at 47-49.

number had increased to 1999 in 1985. *Id;* RT Vol. 86 at 109-111. These totals, however, include wells located outside of the ditch service areas, and wells not pumping from the alluvium of the river. RT Vol. 86 at 108-09; Jt. Exhs. 139, 140.

Since the 1960s, alluvial wells generally have not been drilled. RT Vol. 28 at 68. Both new and replacement wells, inside and outside of the ditch service areas, have been drilled into the Ogallala formation. *Id.* at 68, 85. The river alluvium is now largely dewatered, and the deeper Ogallala wells are not even perforated in the alluvium. *Id.* at 64. Water levels in the Ogallala have been declining since the 1950s, from 20 to 90 feet depending upon the location. *Id.* at 73; Jt. Exh. 140 at 1. In 1950, an average Ogallala well pumped between 1,500 and 2,000 gallons per minute. Today, the typical yield of an Ogallala well ranges from 650 to 1,000 gpm. RT Vol. 28 at 81. For the period 1968-85, pumping within the canal company service areas has averaged about 79,400 acre-feet annually, reaching a high of 149,800 in 1981. Kan. Exh. 327 at 9, Table 10A. Surface diversions during this period averaged 58,400 acre-feet annually. *Id.*

C. Impacts of Pumping in Kansas.

In 1977 the Kansas Division of Water Resources entered into a five-year cooperative investigation with the USGS. The purpose was to better define the relationships among groundwater, surface flow and climatic factors along the Arkansas River, and to evaluate the impacts of pumping on streamflow. Jt. Exh. 139 at 3. The study was divided into two phases, Phase I being upstream of the Bear Creek Fault zone, and Phase II downstream. The results were published in 1983 for Phase I and 1985 for Phase II. Jt. Exhs. 139 and 140, respectively.

As part of its Phase I investigation upstream of the Bear Creek Fault zone, the USGS found that average streamflow at Syracuse (about 15 miles below the Colorado-Kansas border) had declined from 173,000 acre-feet during 1951-69 to 65,000 acre-feet during 1970-79. Jt. Exh. 139 at 1. During the 1970s, pumping in this reach of the river increased from 20,000 acre-feet in 1970, with fewer than 100 wells, to nearly 65,000 acre-feet in 1979, with some 160 wells. *Id.* at 53. Static water levels in the alluvial aquifer declined during the 1970s by about 4 feet. *Id.*

In the early postcompact years, i.e., 1951-69, this portion of the river was in hydrologic equilibrium. About as much water came into the stream-aquifer system as was discharged from it. *Id.* at 55. Since the "prolonged streamflow reductions" beginning about 1970, the USGS found that discharge exceeded recharge. *Id.* The USGS concluded that water levels and streamflow within the study area were "more directly affected by the reductions in incoming streamflow . . . than by either the smaller than average amounts of annual precipitation or the increased pumpage during the 1970s." *Id.*

In the area downstream of the Bear Creek Fault zone, under predevelopment conditions the groundwater levels and hydraulic head (pressure) in the Ogallala Aquifer resulted in upward leakage into the alluvial aquifer and the Arkansas River. RT Vol. 30 at 67; Jt. Exh. 140 at 22. But this condition changed with increased pumping, and during the 1970s water leaked from the upper down into the lower aquifer. RT Vol. 30 at 68; Jt. Exh. 140 at 8, 22. Phase II of the USGS study embraces this area from the fault zone to a point slightly downstream of Garden City, a distance of about 45 miles. Jt. Exh. 140 at 2, 7.

The lower or Ogallala Aquifer is the source for virtually all of the groundwater pumped in this Phase II area. *Id.* at 8. One study cited by the USGS estimated that in 1980 approximately 2,900 wells pumped about 738,000 acre-feet of water. *Id.* at 11. The aquifer is being heavily mined. In 1980 the USGS model indicated that 307,600 acre-feet were withdrawn from storage. *Id.* at 51. The upper or alluvial aquifer has been dewatered since the mid-1970s. *Id.* at 48. However, considering the reach of the Arkansas River from the Bear Creek Fault zone to Garden City as a whole, the river has been a losing stream since 1923. *Id.* at 15. Most of the loss (recharge to the alluvial aquifer) from 1923-70 occurred in Finney County, but during the 1970s the river also lost flow throughout most of Kearny County. *Id.* This was the result of decreased river flow from upstream, and from pumping which lowered groundwater levels and reduced or eliminated groundwater contributions to the river. *Id.*

Kansas did not aggressively address these conditions until January of 1977 when the chief engineer of the Kansas Division of Water Resources declared a moratorium on the approval of new well applications in a 500 square mile area along the river in Hamilton and Kearny Counties. RT Vol. 37 at 53. (The moratorium did not include Finney County. Jt. Exh. 140 at 2.) Well permits have been required only since 1978. RT Vol. 28 at 6; RT

Vol. 37 at 27, 32. In 1986, as a follow-up to the moratorium, Kansas established an intensive groundwater use control area (IGUCA) which generally conforms to the alluvium from the Stateline to Garden City. Jt. Exh. 82 at 26-27. This area was designated under a 1982 Kansas statute authorizing the chief engineer to act when groundwater levels have declined "excessively," or pumping exceeds the rate of recharge. *Id.* at 3. Under this authority, David L. Pope, the Kansas chief engineer and a principal witness during the trial, closed the IGUCA to any new appropriation of groundwater or surface water, except for domestic uses. *Id.* at 29. There has been no action, however, to restrict the quantities of water pumped from wells with existing permits. RT Vol. 37 at 56.

Colorado could be affected by the pumping in Kansas in two ways. First, under the compact and absent the 1980 Operating Plan, neither state is allocated a specific share of the water stored in the conservation pool in John Martin Reservoir. Instead, the stored water is a common resource to be released ". . . upon demands by Colorado and Kansas concurrently or separately at any time during the summer storage period." Article V-C. Helton and others testified that the development of postcompact wells in Kansas reduced the usable flow of the river in Kansas by increasing seepage or what was termed "transit losses." Indeed, this appears to be true, although the extent may be in issue. In any event, the result could mean additional demands by Kansas on the stored waters in John Martin Reservoir, thereby reducing the amount available to Colorado.

However, Helton testified that these potential consequences have not in fact occurred. He said that during the 1970s, any increased percolation of river water in Kansas would not have affected its use of conservation storage. At that time, he thought, Kansas would have called for the release of all such water without regard to transit losses. RT Vol. 115 at 33-34. Helton testified that before the 1970s river flows were not substantially impacted by the Kansas wells. *Id.* at 33. And, of course, after the 1980 Operating Plan was in effect Kansas had its own storage account in John Martin Reservoir and its use of that water did not affect Colorado's storage account. In short, the evidence shows that increased pumping in Kansas has not adversely impacted Colorado's supply.

Secondly, pumping in Kansas could affect the determination of usable flows at the Stateline. Under Spronk's analysis, flows contributing to increased groundwater recharge were treated the same as diversions. This was not true in the Durbin-Larson analyses. Each of these latter experts calculated flows for groundwater recharge on the basis of precompact conditions. However, I am recommending against using the Spronk methodology for this and other reasons, and increased pumping in Kansas will not affect the determination of usable flow at the Stateline if my recommendation is approved.

SECTION XVIII

KANSAS' ORIGINAL HYDROLOGIC-INSTITUTIONAL MODEL

During the preparation of this case, and during the first part of the trial, the chief technical witness for Kansas was Timothy J. Durbin. Mr. Durbin holds a Master of Science degree (1971) in civil engineering from Stanford, and is a former District Chief, California District, for the USGS. He joined the USGS in 1972 and has substantial experience in hydrologic modeling, primarily in California and Nevada.[73] He had no prior experience with the Arkansas River. He left the USGS for private practice in 1984, and soon joined the national firm of S. S. Papadopulos & Associates in charge of their Davis, California office. He began working for Kansas on this case, as part of the Papadopulos firm, in 1985. RT Vol. 39 at 65. In 1989 the Davis office of the firm was split off, and Kansas chose to remain with Durbin as its primary expert.

Durbin began his investigation on behalf of Kansas by examining seven possible causes of the depletions of Stateline flows: declines in High Plains runoff; declines in High Plains precipitation; changes in basin inflows; post-compact pumping in Colorado; the Winter Water Storage Program; the 1980 Operating Plan for John Martin Reservoir; and increased phreatophyte consumption. RT Vol. 39 at 66-67.

Durbin concluded that High Plains runoff was only a small portion of the overall water supply of the river and

[73] A complete statement of his qualifications and experience is found in Kan. Exh. 485.

that changes in such runoff, either because of precipitation or land use practices, were not an explanation for Stateline depletions. RT Vol. 39 at 70. Those factors were dropped from consideration and Durbin concentrated his investigation on the five remaining potential causes of the declines in Stateline flows. Three separate approaches were used: a statistical analysis, a water budget analysis, and the hydrologic-institutional ("H-I") model. RT Vol. 39 at 72.

From the statistical and water budget analyses, which are both fairly traditional approaches, Durbin concluded that for a given basin inflow the Stateline flows were substantially lower in the late postcompact period (1970-85) than in the earlier postcompact period (1948-59), and that increased consumption within Colorado had caused the decline. Kan. Exh. 60*; RT Vol. 40 at 43-44; Kan. Exh. 99G; RT Vol. 41 at 120-21. So long as supply remains constant,[74] Durbin testified, streamflow depletions at the Stateline mean that somehow consumption has increased within Colorado. RT Vol. 39 at 73; RT Vol. 41 at 23-24. Durbin acknowledged, however, as did later Kansas experts, that the statistical plots did not provide an explanation for the decline, and that the water budget analysis did not quantify the effects of possible individual causes, e.g., pumping, the WWSP, or increased consumption by phreatophytes. Durbin testified that the

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[74] There has been no showing of a significant decline in inflow to the mainstem of the Arkansas River. Gaged tributary inflow shows a small decrease; the evidence on ungaged tributary inflow is in sharp conflict.

H-I model was developed in order to distribute the overall effects to individual causes. RT Vol. 39 at 73. Kansas' replacement expert Larson also confirmed that the only way to quantify the effects of an individual cause of depletions was through the modeling analysis. RT Vol. 127 at 135.

A. The Basic Structure of the H-I Model.

The H-I model is a computer model which receives input in the form of certain hydrologic data and institutional conditions, as well as the output of other analyses. The H-I model attempts to integrate both surface water and groundwater processes in the Arkansas River Basin from Pueblo to the Stateline. It represents an enormously difficult task, the complexities of which may not have been fully appreciated when Durbin began to develop the basic structure of the model.[75]

Mr. Durbin relied, somewhat optimistically I believe, upon an earlier model developed by the USGS for the same reach of the Arkansas River. Jt. Exh. 78. This model, too, integrated both groundwater and surface water operations, and according to Durbin was a hydrologic-institutional model. The report on the earlier USGS model was issued in 1974, and it covered the period from 1941 to 1965. However, the USGS model was designed only to make a broad assessment of twenty-four different water

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[75] In 1989, Dr. Lawrence J. Lefkoff, who received his doctorate degree from Stanford in 1988, began to assist Mr. Durbin, and ultimately became primarily responsible for certain portions of the H-I model analyses.

management plans. It was neither required nor intended to provide the level of accuracy and detail demanded in an adversarial trial. The simplifications used reflected the limited purpose of the model. For example, the model did not represent any winter diversions by Colorado ditches; it did not represent off-channel storage reservoirs; it did not represent conservation storage events in John Martin reservoir during the summer; and well pumping was not actually determined, but rather was based upon allowing wells to pump to their maximum capacity in order to satisfy the unmet demand of all the land under the respective ditches. This overestimated actual pumping. RT Vol. 86 at 139-42.

Typically, hydrologic models are used to predict future flows or conditions in light of certain assumed changes, such as the proposed construction of a reservoir. If the model has been properly verified to match historical conditions, reasonably reliable results can be expected. The computer modeling process is widely used and accepted. Indeed, it seems that no major water problem can now be solved without a model, even though models generally rely upon the future repetition of a past hydrologic cycle that is not likely to be the same. But in this case, the model must be used to unravel a more difficult problem than is usually addressed. The task is to determine what usable Stateline flows would have occurred if in fact certain actual historical events had been different, namely, if postcompact pumping had not increased, or if the Winter Water Storage Program had not been instituted. Not only are there critical data problems in the more distant years, but the process even requires assumptions about what people would have done if their actual behavior had not been allowed.[76]

Dr. Freeze testified that groundwater models are generally accurate only between 10 and 20 percent. RT Vol. 70 at 137, 154. When groundwater models are integrated into an overall model involving surface flows, he testified that "large errors" could be expected and that they could exceed 20 percent. RT Vol. 70 at 150-54. Modeling a system like the Arkansas River would be "difficult," he said, though he acknowledged it would not be impossible. RT Vol. 70 at 153; RT Vol. 105 at 42. Asked about the sharp differences in modeling results in this case, Dr. Freeze said that the experts on both sides "are extremely well regarded," and are among the "best experts that there are in the country." RT Vol. 105 at 45. However, besides the inherent difficulties in trying to reproduce conditions over 36 years along 150 miles of river, and a certain lack

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[76] Dr. Robert Allan Freeze, one of the pioneers in the application of digital computer models to groundwater problems, put it this way:

> "The point you are making is that in classical modeling we are usually trying to go into the future. The what-if games we play in the classical model usually involve calibrating against what happened up to this point in time. Then predicting the future, what would happen if somebody did something different in the future. I understand the what-if games you are playing here. What-if things that happened in the past hadn't happened. So it is a different kind of game, yes." RT Vol. 105 at 41.

Dr. Freeze is a professor in geological engineering at the University of British Columbia who served on the Technical Advisory Committee organized by Colorado. His exceptional qualifications are found in Colo. Exh. 670.

of reliable data, he thought that the litigation process was partly responsible for the wide disagreements among the experts. It is a "new world" for such experts, he said, and a process that "drives us apart." RT Vol. 105 at 46.

The H-I model is actually an integrated family of models, modules and sub-routines. RT Vol. 42 at 29-30; RT Vol. 87 at 34. Included are two groundwater models for the valley fill aquifer and eight for the bench areas. For two particularly long canals (Fort Lyon and Amity), groundwater models were also developed to calculate individual response functions for canal seepage. Runoff from ungaged tributary basins was estimated by a rainfall-runoff model, and annual values from that model were distributed into monthly values through a special version of the H-I model, sometimes referred to as the "GLOBAL" version. The model predicted surface diversions, dividing the river into 18 reaches, and using 89 separate water rights for 23 canal companies. Another subroutine calculated the amount of water consumed by crop evapotranspiration, and the amount of applied water returned to the river as surface runoff or recharged to the groundwater system.

The study period for the H-I model runs from January 1950 through December 1985, a total of 432 months. Output from the model is provided at monthly time intervals. The model accounts for all major diversions from the Arkansas River between Pueblo and the Stateline, and for irrigation pumping from both the valley fill and bench aquifers. The model represents the off-channel reservoirs, as well as the operations of John Martin and Pueblo Reservoirs. Transmountain water which enters the system at Pueblo is accounted for. Consumption by phreatophytes and river and reservoir evaporative losses are considered, as well as canal and lateral seepage losses. Irrigation return flows to the river, both on the surface and through the groundwater system, are represented for each canal service area. Tributary inflows from the major tributaries are included, along with precipitation within the study area. Water consumption processes, such as crop evapotranspiration and noncrop evapotranspiration are also included.

B. Original Results of the H-I Model.

The H-I model evaluated four separate institutional conditions: postcompact pumping; the Winter Water Storage Program; transmountain water imports; and the 1980 Operating Plan for John Martin Reservoir. The inclusion or exclusion of these four institutional conditions as they were used in various model runs were often described as being controlled by "switches." In the various exhibits, the "on" position for each of these institutional conditions is signified by an "H" (historical conditions). The "off" position is signified by a "C" (compact conditions). When transmountain deliveries are excluded, the exhibits show "0" (no deliveries).

Model results are calculated as the difference between a pair of runs. For example, to show the Stateline depletions caused by postcompact pumping, the first run of the model is made on the basis of actual historic conditions, that is, all switches are "on." The second run would have a single change, that is, postcompact pumping would be reduced to the 1948 compact level. The difference in Stateline flows would represent the depletions caused by the additional postcompact pumping. This example is shown as Comparison "F" on Kan. Exh. 111* (12/6/90). Total depletions from postcompact pumping as shown by this model run, without taking accretions into account, amount to 1,581,000 acre feet for the 1950-85 period. These are depletions of total flow, not usable flow.

Durbin relied upon Comparison "C" of Kan. Exh. 111* (12/6/90) to show the combined effects of postcompact pumping in Colorado and the Winter Water Storage Program. RT Vol. 45 at 81. Under this scenario, total depletions without considering accretions amounted to 1,427,000 acre-feet. After deducting accretions, the net depletions were 1,029,000 acre-feet. In Durbin's view, the issue of whether or not accretions should be taken into account was in part a legal consideration and in part a hydrologic consideration. The hydrologic aspect was that although accretions in a given month could be isolated, they would not necessarily make up for depletions in another month. RT Vol. 44 at 120. The depletions shown on Kan. Exh. 111* (12/6/90) were to total, not to usable, flow.

The original Kansas claim, as confirmed during Durbin's testimony and based on the H-I model, was 917,000 acre-feet. RT Vol. 45 at 124-25. This represented depletions to usable flow over the 1950-85 period resulting from the combined effects of postcompact pumping and the WWSP. Kan. Exh. 112* (12/6/90) Comparison "C"; RT Vol. 45 at 125. This analysis considered that the 1980 Operating Plan for John Martin Reservoir was in effect during both of the comparison runs. In contrast, and based on the revised version of the H-I model, the present Kansas claim for depletions to usable flow caused by pumping and the WWSP together, comes to 489,000 acre-feet.[77] Kan. Exh. 111***.

C. Colorado's Criticism of the Original Version of the H-I Model.

Kansas complains that Colorado in its opening post-trial brief spent some 150 pages attacking Durbin and the original version of the H-I model. Kansas calls it "largely a waste of the Special Master's time" because substantial revisions were made to the H-I model, and to Durbin's analysis, by the Kansas replacement experts. Perhaps more aptly, Kansas also noted that Colorado's emphasis tended to obscure the fact that its own water budget analysis showed total depletions of approximately 583,000 acre-feet resulting from postcompact pumping.[78]

The major changes in Kansas' position and evidence cannot be ignored. For some five years the Kansas experts worked to accumulate the necessary data and to develop the H-I model in order to support the state's claims. Yet after Colorado's cross-examination during trial uncovered numerous errors and shortcomings in the Kansas

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[77] The comparison with 917,000 acre-feet is not exact because the depletion figure of 489,000 acre-feet assumes that the 1980 Operating Plan was not in effect, either during the historical run or the combined effects run. The comparable figure from the revised H-I model is 496,000 acre-feet (1980 Plan included in both runs). Kan. Exh. 651, comparison 4.

[78] Colo. Exh. 135* at 6.1; RT Vol. 115 at 73-75. These are depletions of total flow, however, not depletions of usable flow.

evidence[79], and after the trial recess caused by Durbin's hospitalization, Kansas' replacement experts testified to substantially different conclusions than those resulting from the original H-I model. Brent E. Spronk, one of Kansas' replacement experts, testified openly that the results of the original H-I model were not reliable.[80] As part of its replacement case, Kansas made numerous changes to the original H-I model, but did not alter its basic logic and structure. RT Vol. 88 at 52. In addition, Kansas submitted 63 revised exhibits and 10 new exhibits. As a result of these changes, Kansas cut its claimed depletions approximately in half. Under Durbin, the Kansas claim was 917,000 acre-feet for both pumping and the WWSP. It is now 489,000 acre-feet. Kan. Opening Br. at 128.

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[79] The errors were not confined to the H-I model. Of some 25 exhibits prepared to support Durbin's statistical analysis, all contained errors. Durbin prepared revised exhibits for 24 of these, but there were also errors in the revised exhibits. RT Vol. 48 at 4-17. Dr. Lefkoff apparently supervised the preparation of these exhibits. RT Vol. 47 at 83, 87.

[80] Spronk said: "I don't believe that those results [of the H-I model] are reliable or accurate in terms of the magnitude of impact that they showed at the state line . . . ." RT Vol. 88 at 93-94; RT Vol. 89 at 103-04. Spronk was one of the experts involved early in the preparation of the Kansas case, but his role then was confined largely to developing raw data, and to work on the operation of Trinidad Reservoir (decided on motion, in Part III of this Report). Spronk holds a 1978 master's degree in civil engineering from Colorado State University, and is president of Spronk Water Engineers. His resumé is Kansas Exhibit 481, and his experience includes an earlier report on the Arkansas River done when he was employed by Simons, Li & Associates. Jt. Exh. 88.

Colorado assigned one of its experts, Dewayne R. Schroeder, solely to the task of reviewing and understanding the H-I model.[81] Schroeder was ultimately able to extract the specific data used in the model as well as the values used for such parameters as canal seepage, tailwater runoff and noncrop consumptive use, each of which was improper in his view. As a result of his analysis, Schroeder also identified 16 separate coding errors and inappropriate assumptions in the original H-I model. RT Vol. 87 at 53-67. There is no need to address them in detail here, except perhaps to note that the coding error with respect to monthly inflow at Pueblo dramatically changed the impacts of the WWSP calculated by the model. RT Vol. 87 at 54, 67. The validity of these criticisms was essentially confirmed by Kansas' replacement experts, who responded to each of them.

However, Schroeder and other Colorado experts testified to additional deficiencies in data and model structure that were not changed in the revised version of the model. These included reliance upon the rainfall-runoff model to estimate ungaged tributary inflow; failure to calibrate the groundwater model to water levels; treatment of the groundwater aquifer as a linear system; unreasonable estimates of deep percolation; failure to divide the river into sufficient reaches; failure to account for precipitation in the logic used to predict Kansas'

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[81] Schroeder is an engineer employed by the Colorado Division of Water Resources. Since 1984 he has been head of the Chief Engineer's Special Studies Unit, concerned primarily with groundwater modeling.

demands for releases from John Martin Reservoir; inaccurate assignment and distribution of pumping and irrigated acreage figures among the various canal companies; and underestimation of water consumption by phreatophytes.

Dr. Devraj Sharma,[82] Colorado's expert in groundwater modeling, was particularly critical of Durbin's efforts to calibrate Kansas' groundwater models. Durbin presented a series of hydrographs to show the match between predicted and observed groundwater levels. Kan. Exhs. 89C, 89D. But Dr. Sharma pointed out that of the 106 hydrographs shown, 30 had been "clipped" so as to appear more favorable than they really were. RT Vol. 81 at 7-23; Colo. Exh. 809. When Sharma plotted actual predicted water levels, instead of merely changes in levels, it appeared that 30% of the wells showed water levels that were either above the surface of the ground, or were below bedrock. Dr. Freeze did not consider such a model to be properly calibrated. RT Vol. 105 at 53-54.

While Kansas' replacement experts made a number of changes to Durbin's groundwater models, they did not recalculate the hydrographs used by Durbin. RT Vol. 100 at 45-47. Larson testified that it would have been a "relatively difficult step to go through," and the hydrographs

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[82] Dr. Sharma's broad experience and qualifications are summarized in Colorado Exhibit 668*. His Ph.D is from London University, and he has been a visiting professor at a number of universities around the world. He has extensive expertise in mathematical modeling, and developed the groundwater models used by Colorado in its water budget analysis. He was with Dames & Moore from 1975 to 1983 and moved to Denver in 1978. Currently, he is president of Principia Mathematica Inc.

were only one of several bases for judging the adequacy of the groundwater component of the revised H-I model. *Id.* Instead, Larson calibrated against winter streamflows, a procedure that Colorado experts thought should have been coupled with comparisons to measured groundwater levels. RT Vol. 105 at 52-53, 59; RT Vol. 106 at 26. Schroeder testified that the H-I model always tended to overpredict diversions, and that its problems "go quite deep." RT Vol. 111 at 62.

The Colorado view that inherent flaws still remain in the H-I model, even after the revisions that have been made, was also shared to some extent by experts for the United States. Their testimony is discussed in Section XXII on the WWSP.

SECTION XIX

KANSAS' REPLACEMENT CASE

Following the continuance occasioned by Mr. Durbin's illness, Kansas resumed its case in chief. A "replacement case" was presented through five "replacement experts." Three members of the replacement team had testified earlier (Spronk, Book, Lefkoff), but they now played expanded rolls. The two other replacement experts were Steven P. Larson and Thomas A. Prickett. In addition to making numerous corrections and revisions to the H-I model, Kansas lodged 63 revised exhibits and ten new exhibits. Included were revisions to Durbin's statistical and water budget analyses. Some of the lodged exhibits reflected necessary corrections, but other model changes and revised exhibits actually represented an effort to improve Kansas' case, responding to matters that had been raised on cross-examination.

Colorado moved to exclude a number of the lodged exhibits and to require that portions of the replacement case be presented only in rebuttal. Colorado argued that Kansas had taken advantage of the continuance "to redo parts of its case," and that was not the purpose of the continuance. RT Vol. 88 at 29-30. To be sure, there was some merit in Colorado's reaction, but in the last analysis I concluded that it was more important to have the best evidence available in the record. Colorado's motion was denied. Any prejudice to Colorado was sought to be remedied by giving Colorado whatever time was necessary to prepare proper cross-examination and to respond as part of its surrebuttal case.

The chief replacement witness was Steven P. Larson. He holds a 1971 Master of Science degree in civil engineering from the University of Minnesota. From 1971 to 1980 he was employed by the USGS and had extensive experience there in the research and development of models, principally groundwater models. In 1980 he joined the consulting firm of S. S. Papadopulos & Assoc. as a vice-president. That is his present employment. As a member of that firm he has had considerable experience in major litigation involving the interaction between groundwater and streamflows on the Pecos and Rio Grande Rivers. He has also done work for the Colorado state engineer.[83]

When Kansas engaged the Papadopulos firm to assist in this case, Durbin essentially acted as the project manager. RT Vol. 98 at 84-85. Larson was involved only as an advisor to Durbin and as a reviewer. After Durbin left the Papadopulos firm in 1989, Larson continued to act as an advisor, but on a relatively limited basis. *Id.* at 85.[84]

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[83] His full qualifications appear in Kan. Exh. 488.

[84] As a member of the team of replacement experts, Larson was asked to review the statistical and water budget exhibits presented by Durbin; to assist in the review and revision of the H-I model; and to draw conclusions as to whether and to what extent streamflows had been depleted by postcompact pumping in Colorado and by operation of the Winter Water Storage Program. RT Vol. 98 at 86.

A. Review of the Statistical and Water Budget Analyses.

Kansas' replacement case included revisions to its statistical and water budget analyses, as well as to the H-I model.[85] The revised exhibits presenting the results of the statistical and water budget analyses corrected numerous errors that had been identified in earlier versions of the exhibits, and contained slightly different time periods for comparison. The exhibits continued, however, to present data comparisons of precompact and postcompact conditions, and early and late postcompact years. The revised exhibits continued the use of statistical plots, the use of regression analyses, and in part the use of a parallel line model. Larson testified that these revised exhibits supported the general conclusions reached earlier by Durbin, namely:

1. Stateline flows were lower in the postcompact period than in the precompact period for any equivalent amount of annual basin inflow. RT Vol. 98 at 89.

2. Stateline flows at any particular level of basin inflows were lower in the late postcompact period than in the early postcompact period. RT Vol. 98 at 100.

3. There is a trend of decreasing Stateline flows associated with increased amounts of pumping. RT Vol. 98 at 101.

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[85] See especially Kan. Exhs. 59**, 60**, 61**, 63**, 70**, 99D**, 99F*, 99G**, 100D**.

4. There is a tendency for pumping to increase as basin inflows decrease, that is, as less surface water is available for diversion. RT Vol. 98 at 106, 109.

5. "Consumption" in Colorado increased in the late postcompact period relative to the early postcompact years.[86] RT Vol. 98 at 117, 125-26.

Larson acknowledged, however, as had Durbin, that the various statistical plots did not explain the causes for the differences shown. This was the reason that it was necessary to move into modeling. RT Vol. 98 at 90; RT Vol. 100 at 19; RT Vol. 127 at 135. Nonetheless, factors identified by Larson that might account for the statistical differences included the operation of John Martin Reservoir, pumping in Colorado, the Winter Water Storage Program, and the increased water use by phreatophytes.

In connection with the water budgets, it should be noted that ungaged tributary inflow was based upon the runoff predicted by Kansas' rainfall-runoff model, and the consumptive use by phreatophytes reflected the earlier testimony by Kansas' expert. Both of these items are disputed by Colorado. Overall, Larson relied upon the statistical and water budget analyses to provide "sort of first-order estimates," and used them mostly "to look at trends in the relationships between the variables." RT Vol. 100 at 17-19, 50-51. However, he also testified that the

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[86] "Consumption" was simply the residual in the water budgets and included many conditions in addition to consumptive use by crops. RT Vol. 98 at 115.

depletions shown by the H-I model corresponded generally with the quantities in the water budgets. RT Vol. 99 at 92-96.

B. Revisions to the H-I Model.

Significant changes were made in the H-I model. RT Vol. 100 at 47; RT Vol. 110 at 104. Some 900 lines were added to the model code. Kan. Exh. 639; Colo. Exh. 765. An eight-page list describes 53 changes to the model code. Kan. Exh. 640. Another list shows the data files that have been changed. Kan. Exh. 641. Schroeder acknowledged that the sixteen coding errors and inappropriate assumptions previously identified had generally been corrected. RT Vol. 110 at 107-117. He testified that there were no coding errors in the revised model. RT Vol. 139 at 117.

However, many other changes were also made. Principally, the replacement experts no longer used the special version of the original H-I model to estimate monthly tributary inflow, but rather inserted the annual values predicted by the rainfall-runoff model as direct input into the revised H-I model. RT Vol. 89 at 128; RT Vol. 96 at 43. In connection with the groundwater models, the replacement experts did not calibrate against changes in ground water levels as Durbin had done, but rather used winter streamflows for their calibration. RT Vol. 100 at 45-47. Larson testified that they did not go back and recalculate the clipped hydrographs because of the relative difficulty of that step, and because "it was only one of several bases for judging the adequacy of the ground water component of the [H-I] model." RT Vol. 100 at 47. He said that the groundwater models should be viewed as part of the H-I system, not as separate units, and that evaluating the overall results of the H-I model included an evaluation of groundwater conditions and the response functions derived from the groundwater models. RT Vol. 99 at 76-77.

Initially, the replacement team was not able to calibrate the H-I model as it had been corrected and revised. RT Vol. 88 at 79; RT Vol. 95 at 139. Predicted diversions under the historic simulation of the model were much higher than the observed data. Calibration was achieved only through the insertion of two "calibration factors," namely, a diversion reduction factor and a canal capacity reduction factor. Both of these factors restricted model diversions by certain water-short ditches.

The diversion reduction factor was applied seasonally to the Amity and Colorado Canals, to the Fort Lyon junior rights, and to the Great Plains reservoir system. RT Vol. 88 at 78. This calibration factor reduced diversion amounts between 15 and 25 percent when applicable. RT Vol. 88 at 82. In addition, the canal capacity reduction factor artificially reduced, for model purposes, the capacities of a number of major canals below their known actual physical capacities. Colo. Exhs. 695 and 903. The effect of both these factors was to limit diversions by certain canals at certain times even though water was available in the river, even though the canals had both the rights and physical capacities to divert, and even though the need for water was apparent. Moreover, water thus required by the model to pass downstream was routed directly into the conservation pool at John Martin Reservoir or down to the Stateline, and was treated as being unavailable for use by any intervening diverter. RT Vol. 111 at 55. Dr. Lefkoff testified that this constraint was necessary in order to achieve calibration. RT Vol. 95 at 139. Larson and Spronk testified to the same effect. RT Vol. 127 at 52-57; RT Vol. 128 at 38-42; RT Vol. 88 at 79.

Schroeder acknowledged that the H-I model, as revised, was calibrated. RT Vol. 138 at 98. However, he objected strenuously to the way in which calibration had been accomplished. Use of the diversion and canal capacity reduction factors, in his opinion, were inappropriate because they did not "represent any physical process."[87] RT Vol. 111 at 52. He testified that model results are not necessarily reliable simply because the model has been calibrated, that is, simply because predicted and observed values match reasonably well. RT Vol. 138 at 100. Dr. Freeze agreed that a model can appear calibrated but still be in error because of paired parameters, both of which are in error. RT Vol. 70 at 136.

Kansas experts, however, defended the use of these calibration factors as appropriate modeling techniques. RT Vol. 127 at 52 *et seq*. Larson testified that the use of calibration parameters in all forms of modeling analyses is common practice. *Id*. They are designed to improve a model's performance and often are required to compensate for lack of basic data. They need not be physically based. *Id*. at 53. Larson noted that the Colorado water budget employs such a parameter called "maximum farm

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[87] Helton testified that the application of the diversion reduction factor was the "most important deficiency" in the revised H-I model. RT Vol. 115 at 45.

efficiency." *Id.* at 54. It is not physically based, but operates at times to constrain consumptive use. *Id.* at 54-55. According to Larson, calibration is not simply a mechanical process, but must include "the judgment and experience of the analyst . . . in order to get reasonable results." RT Vol. 98 at 134.[88]

C. Calibration Results of Revised H-I Model.

In evaluating the performance of the revised H-I model, the Kansas experts focused on matching predicted and observed streamflows and diversions because that is what the model was designed to determine. Larson illustrated the model's calibration mainly through two exhibits: Kan. Exh. 566G*-566L* and Kan. Exh. 568*. The first of these exhibits includes a series of charts or line diagrams illustrating the comparison between model calculations of streamflows and actual observed flows at a number of different points along the Arkansas River. Larson testified that the revised model was able to replicate streamflow conditions reasonably well. RT Vol. 99 at

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[88] Larson also pointed to a number of USGS modeling studies along the Arkansas River that generally support the approach used by Kansas. Included are studies that combine surface and groundwater models, that treat the system as linear for modeling purposes, that use unit response functions to simulate the interaction between groundwater and surface flows, that predict diversions, and that are calibrated against streamflows. Jt. Exhs. 74, 75, 76, 77, 78; Kan. Exhs. 441, 442, 668, 687. All of these approaches or assumptions, when employed by Kansas in the H-I model, invoked criticism from Colorado experts.

81-88.[89] While the scale of these charts is quite small, the correspondence between predicted and measured flows seems reasonable. However, Helton produced tables of numerical amounts of flow that put in question the model's performance at points upstream from the Stateline. Colo. Exhs. 908, 996. These are discussed later.

Larson also testified with respect to Kansas Exhibit 568*, which is a line chart and scatter diagram illustrating the correspondence between observed and predicted diversions. He thought that the revised model did a "very good job" of simulating total diversions in the Arkansas Valley in Colorado, despite the criticisms about the use of diversion reduction factors. RT Vol. 99 at 90.

Based upon these exhibits, together with Kansas Exhibits 570* and 571*,[90] Larson testified that the revised H-I model was sufficiently calibrated to make comparative runs between historical or baseline conditions and alternative institutional conditions.[91] RT Vol. 99 at 92.

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[89] His characterizations ranged from "quite well" upstream, to "reasonably well" at midstream, and to "reasonably good" at the Stateline.

[90] These exhibits divided total diversions into upstream and downstream comparisons.

[91] Dr. Sharma, Colorado's expert in groundwater modeling, testified that a model should not only be calibrated but also "verified." This process involves holding back certain historical data from the calibration process, calibrating the model using only the remaining data, and then comparing predicted model results with the withheld historical data. Larson termed this procedure a luxury, "very rarely done in practice." RT Vol. 98 at 139. He testified that this case presents a very complicated problem where we have to use "all of the data we can get our

Larson was unwilling to agree that calibration determined whether or not a model was "accurate" or could be "reliably used." He defined calibration as "trying to obtain the best estimates of the parameters, so when we used the model, we get the best estimate of the results." RT Vol. 98 at 140; RT Vol. 128 at 68-69. It was his opinion that "we have obtained the best parameter set that we can given the information we have available to us. So as a result, the calculations of the model will represent my best estimate of conditions along the Arkansas River Valley with respect to this particular model. And then when we use it to calculate conditions for an alternative scenario, that would represent my best estimate of what that scenario would be." RT Vol. 98 at 140. Spronk also testified that the model results provide the best estimates of depletions.[92] RT Vol. 88 at 118.

Larson recognized the presence of uncertainty in the revised H-I model results. RT Vol. 99 at 29. But he testified that when two model results are subtracted one from the other in order to get the difference, the uncertainty associated with the difference will not necessarily be as great as the uncertainty in each of the individual model runs. *Id.* The reason is that many of the approximations used in the model are the same in both model runs. If there is error in these data, Larson testified that such

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hands on to do the calibration." RT Vol. 99 at 80. Dr. Freeze had not examined either the Kansas or Colorado models, but he said that verification is "good practice." RT Vol. 70 at 139.

[92] Dr. Freeze agreed there is no "right answer" from a calibrated model, only a best estimate of the right answer given the data you have and the methods used. There is "a range of answers," he said. RT Vol. 70 at 146.

correlated errors "will tend to cancel out." RT Vol. 99 at 30. He termed this "canceling effect" an important factor in considering how the revised H-I model is used in this case.[93] *Id.* The situation would have been different, he pointed out, if Kansas had tried to compare the alternative institutional condition not with another model run, but rather with actual measured historical data. *Id.* The United States expert, Charles W. Binder, agreed that the parallel run theory and the consequent cancellation of error is a "common method that is used in modeling." RT Vol. 118 at 100. However, for reasons discussed in Section XXII, he did not believe it applied in the analysis of the Winter Water Storage Program. *Id.* at 101.

Both Colorado and the United States introduced evidence comparing actual observed Stateline flows with those predicted by the revised H-I model when operated in its historic mode (HHHH, i.e., all institutional switches "on"). Colorado Exhibit 908 shows that for the 1950-85 period actual observed Stateline flows totaled 5,186,496 acre-feet. For the same period of time, the H-I model predicted a total of 4,646,992 acre-feet. Thus, the revised

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[93] Dr. Young Yoon, one of Colorado's expert witnesses, developed a model to isolate the possible impacts of stock ponds and soil conservation measures within the Purgatoire River watershed. His results were derived from a comparison of two model runs, not from a comparison with actual measured flows. RT Vol. 101 at 19-20. In this way, he testified, whatever error might exist in the models would be the same, and any such errors would "cancel out" when you take the difference between the two runs. *Id.* at 22, 25. He added, however, that whether errors cancel depends upon how a model is applied. *Id.* at 76.

H-I model underpredicted total Stateline flows by a little more than ten percent.

The United States prepared similar exhibits, but excluded the extraordinary high flood flows in certain "outlier" months. The months excluded were May and June of 1951 and June, July, August and September of 1965. Excluding these outliers, the United States exhibits show a close correspondence between observed and predicted H-I model flows. For the compact years of 1951-85 actual Stateline flows averaged 119,954.9 acre-feet annually. U.S. Exh. 24*. For the same period of time, the H-I model predicted an annual average of 121,973.3 acre-feet annually. U.S. Exh. 25*. Thus, over the full 1951-85 period, the difference between actual and predicted annual average flows amounted to only 2018.5 acre-feet. U.S. Exh. 26*. The United States exhibits also show that the years in which the model underpredicted are about equal in number to those in which it overpredicted. Moreover, the largest annual underprediction is on the same order of magnitude as the largest overprediction. U.S. Exh. 26*.

Colorado argues, however, that it is not enough for the H-I model to match Stateline flows; that it should also perform well throughout the length of the river. Helton testified to what he called "imbalances" upstream. RT Vol. 133 at 95. Colorado Exhibit 996, which excludes the outlier months of May 1951 and June 1965, shows that the revised H-I model underpredicts streamflows at La Junta by 17 percent; then closely matches observed flows at Las Animas, which is just upstream from John Martin Reservoir; then overpredicts the outflow from John Martin by 7 percent; and farther downstream at Lamar overpredicts by 50 percent. Finally, the model comes back into almost perfect correlation at the Stateline. Helton testified that these imbalances indicate errors in the model, either in the input data, in the assumptions, or in the calibration parameters.[94] RT Vol. 133 at 93-95.

Expert witnesses for the United States generally supported the Colorado criticisms of the H-I model. Their testimony is discussed in Section XXII.

In the final analysis, however, Helton conceded that the revised H-I model does provide a "rough idea" of the impacts of well pumping:

> "With respect to well pumpage, your Honor, I believe the H-I model does give a rough idea of impacts from well pumpage. But I think that rough idea is valid only on a long-term average." RT Vol. 115 at 51.

An anomaly in the case is that the Colorado water budget analysis actually shows greater depletions from pumping than the revised version of the H-I model. Kansas made one run of the H-I model using Colorado's figures for postcompact pumping, which are almost two million acre-feet less than the estimates on which Kansas bases its claim. The results of that run showed total Stateline depletions of 395,000 acre-feet for the 1950-85 period. Kan. Exhs. 642, 643, 742. This total compares to Colorado's estimate of almost 583,000 acre-feet of depletions for the same amount of pumping.

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[94] Helton outlined the errors claimed in some detail. RT Vol. 133 at 102-115.

Colorado does not dispute the comparison.[95] Rather, it tries to blunt the impact by arguing that the causes of the depletions and the conclusions to be drawn from the Colorado analysis are very different. I cannot see that the causes are different. Both studies show the impact on Stateline flows caused by postcompact pumping only, and the amount of that pumping is the same in both of the analyses.

As to the conclusions to be drawn from the Colorado evidence, Colorado points to the opinions of its experts that depletions from pumping upstream of John Martin Reservoir were largely offset by return flows from trans-mountain imports, and that downstream of John Martin depletions were either absorbed by the Colorado ditches or effectively offset by benefits from the 1980 Operating Plan. These conclusions raise possible defenses now, and later may be important in any remedies phase of this case. However, Kansas' point is that the revised H-I model, despite the pounding it has received, produces more conservative results than Colorado's own evidence. Colorado's "conclusions" deal with possible offsets, but do not alter the amount of depletions at the Stateline. Kansas' argument appears well taken, even though it goes too far in claiming that criticisms of the H-I model are thus made "irrelevant." Kan. Answer Br. at 22.

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[95] In its post-trial briefs Colorado acknowledges "that the Colorado analysis shows higher depletions than the results calculated by the H-I Model, as revised [by] the Kansas replacement experts." Colo. Response Br. at 77, 93-94.

D. Results of Revised H-I Model.

The results of the revised H-I model are shown on Kansas Exhibit 111*** and 565***. The latter exhibit provides monthly data which are summarized in Kan. Exh. 111***. A copy of Kansas Exhibit 111*** is included in the Appendix as Exhibit 11.

The depletions shown in Kansas Exhibit 111*** represent total depletions of Stateline flows over the period 1950 to 1985.[96] Moreover, they are depletions of usable flows. What constitutes "usable" flow was determined on the basis of an analysis prepared by Spronk Water Engineers ("SWE" or "Spronk") and presented as part of Kansas' replacement case. RT Vol. 100 at 12 *et seq*. The methodology used by SWE is different from that originally employed by Durbin and results in larger depletions. This issue is fully discussed in Section XXI. The depletions of usable flows do not include any accretions. This issue is also taken up later.

The revised H-I model calculates depletions to usable Stateline flows of 620,000 acre-feet resulting from post-compact pumping in Colorado. This figure does not take into account any offsets resulting from the return flows from transmountain imports. RT Vol. 89 at 76. If such offsets are considered, depletions to usable flows from

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[96] Kansas Exhibit 111*** also includes an estimate of increased depletions caused by "future pumping." This calculation is disregarded here. It assumes a continuation of pumping without regard to appropriate remedies if liability is confirmed. RT Vol. 89 at 72-74.

pumping are reduced to 464,000 acre-feet. Kan. Exh. 651; RT Vol. 90 at 8.

The model shows that depletions from the Winter Water Storage Program considered by itself amount to 40,000 acre-feet. This amount does not reflect any offset for transmountain water. RT Vol. 89 at 76.

The "combined effects" condition tabulated on Kansas Exhibit 111*** represents the depletions caused by both postcompact pumping and the WWSP. Kansas experts determined that it was necessary to analyze the effects of these two changes together because of the potential for interaction between them. Kan. Opening Br. at 101. The combined effect of the two institutional changes proved to be less than the sum of the two analyzed separately. *Id.*; RT Vol. 100 at 21. In addition, this analysis includes an offset for transmountain return flows. RT Vol. 89 at 72. The net amount of depletions of usable Stateline flows under these conditions is determined by Kansas to be 489,000 acre-feet.[97] This appears to be the amount of the Kansas claim,[98] although Kansas has indicated that the appropriateness of any offset due to return flows from transmountain deliveries should be reserved to the remedies phase of the trial. Kan. Letter of 9-3-93 at 10. Moreover, Kansas states that

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[97] If the determination of usable flow is based upon the methodology employed by Durbin, as modified by Larson, depletions from the combined effects of pumping and the WWSP are reduced to 365,400 acre-feet. Colo. Exh. 975; Kan. Exh. 560**; RT Vol. 100 at 11, 15; RT Vol. 99 at 126-42.

[98] See Kan. Opening Br. at 115, 128. This amount is the only finding of depletions of usable flows that Kansas has requested.

the "actual violation" of the compact from pumping is 620,000 acre-feet, that is, the total depletions without acknowledging any offset from transmountain return flows. Kan. Letter of 8-24-93 at 5.

The compact does not cover transmountain imports, and Kansas has acknowledged that it makes no claim to such water. However, the return flows from such imports do add to the Arkansas River supply and do act to offset depletions caused by use in Colorado. We have no assurance that such imports will always continue, nor that the return flows therefrom will remain the same. Yet to the extent that return flows from transmountain imports have actually provided an offset to depletions in the postcompact years, I believe that such evidence is not only relevant now, but is also required.[99]

Kansas did not offer any direct evidence apportioning the 489,000 acre-feet of depletions as combined impact between groundwater pumping and the WWSP.

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[99] I agree with the position taken by the United States in its September 3, 1993 letter:

> "Our understanding of the common sense meaning of Article IV(D) of the Compact is that it prohibits 'actual' rather than hypothetical depletions. Under this common sense meaning, new development will not violate the Compact, even if it has the isolated potential of reducing stateline flows, so long as any potential depletions are offset or compensated for at the stateline by additional water from other new development or other sources such as transmountain return flows. In other words, there is no Compact violation, and no liability, unless the combined effect of all operations, including new development, results in a material depletion of usable flow."

Indeed, Kansas has indicated that there may not be a way to apportion the combined impact. Letter of 8-24-93 at 5.

E. Use of the 1980 Operating Plan in the Revised H-I Model Runs.

In calculating the revised model results for postcompact pumping alone, Kansas included operations under the 1980 Operating Plan in both runs. Kan. Exh. 111***. But in analyzing the combined effects of pumping and the WWSP, as well as the WWSP by itself, the 1980 Operating Plan was excluded. That is, in both the baseline runs and in the "what if" scenarios, Kansas assumed that the 1980 Operating Plan had not been adopted. *Id.* These exclusions are directly contrary to the assumptions made in Kansas' earlier presentation. Durbin testified to the final Kansas claim based upon the results shown in Kansas Exhibit 112* (12-6-90). (See statement by counsel in RT Vol. 45 at 125.) Comparison "C" of that exhibit represents the combined effects of pumping and the WWSP, and shows depletions of 917,000 acre-feet. Comparison "H" shows the impact of the WWSP alone. Both of these runs in Kansas Exhibit 112* (12-6-90) were based upon the operation of the 1980 plan.

I find no evidence in the record explaining the switch change insofar as the combined effects analysis is concerned, although Mr. Spronk discusses the change for the WWSP alone. RT Vol. 88 at 133-35. It is not clear that Colorado opposes the change, but Colorado does point out that the revised assumptions are inconsistent with Kansas' statement of entitlement. Counsel for Kansas wrote:

> "With respect to releases during the period from 1980 to the present, Kansas claims that it was entitled to the releases that would have been made to Kansas *in accordance with the 1980 Operating Plan* absent the depletions above John Martin Reservoir caused by post-Compact well pumping and the Winter Water Program in Colorado." Kan. Letter of 8-24-93 at 3, emphasis added.

This position does not appear consistent with the revised evidence Kansas relied upon to quantify its claim.

With respect to the change made in the WWSP runs, Spronk attempted to provide an explanation. He said that the 1980 Operating Plan would not exist without the WWSP; that the storage in John Martin Reservoir was a result of the WWSP. RT Vol. 88 at 133-35; Kan. Opening Br. at 96. He then reasoned that if the WWSP were not being operated, the 1980 plan also had to be removed from the "what-if" run. And in order not to have two variables in the comparison, it then had to be excluded also from the historical run. The United States draws the opposite conclusion from the fact that the WWSP is "inextricably tied to the 1980 Operating Agreement and helps to make extra water available to Kansas." U.S. Letter of 9-3-93 at 1. It states:

> "We don't see how Kansas can accept a portion of the WWSP water stored under the 1980 Agreement and at the same time demand the same schedule of inflows that would have occurred had the WWSP not been implemented." *Id.*

As the United States properly notes, the Kansas WWSP analysis relies upon a comparison of two hypothetical model runs, neither of which actually happened. U.S. Response Br. at 13-14.

Kansas agrees that the existence of the 1980 Operating Plan should be considered in determining the historical conditions to which the revised H-I model is calibrated. RT Vol. 89 at 80. But Kansas argues that the benefits of the 1980 plan were "separately bargained for," and should not be applied to offset the detriments which arise from a compact violation. *Id.* at 80-81. I agree that the benefits of the 1980 plan, as Helton has quantified them or otherwise, may not be used as a defense to the impact of wells drilled downstream of the Buffalo Canal headgate after 1965. Colo. Exh. 1011, Comparison 9; RT Vol. 133 at 68-75. That was not the intent of the resolution approving the 1980 Operating Plan. However, it does not follow, as a modeling technique, that the 1980 plan must be ignored. The plan now affects results for only five years, but looking to the future, it would become increasingly difficult and less reliable to analyze river conditions on the basis of a storage and release pattern that would not actually have existed over an ever growing number of years.[100]

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[100] It is somewhat anomalous, considering the views of the parties, that the actual inclusion of the 1980 Operating Plan in both of the combined effects runs serves to increase the depletions of usable flow calculated by the revised H-I model from 489,000 acre-feet to 496,000 acre-feet. Kan. Exh. 651, Comparison 4. However, when the WWSP is analyzed separately with the 1980 plan in place, accretions have a major impact. The model results show an increase in Stateline flows of 57,000 acre-feet over the 1976-85 period. *Id.*, comparison 3. There was no evidence, however, on the usability of the accretions.

F. Consideration of Accretions.

The concept of accretions to flows in the Arkansas River was introduced by Kansas. This concept recognizes that releases from upstream storage reservoirs, and pumping from groundwater storage, may at times enhance river flows.[101] This is apart from the fact that the overall impact of groundwater pumping or surface storage may deplete Stateline flows. Kansas exhibits showing the results of both the original and the revised H-I model include depletions alone, and also depletions less accretions. E.g., Kan. Exhs. 111* (12-6-90) and 111***. (Under some model runs, accretions exceed depletions and this result is indicated by parentheses or a minus sign.) Both Durbin and Spronk testified, however, that accretions are relatively infrequent. RT Vol. 45 at 74; RT Vol. 89 at 67; Kan. Exh. 565***. The Kansas replacement case exhibits show depletions not only of total Stateline flows but also of usable flows. Depletions of usable flow, however, do not reflect usable accretions if indeed any exist. RT Vol. 89 at 15, 67; RT Vol. 138 at 75-76. This is in spite of the fact that the revised H-I model does offset daily accretions against daily depletions within the same month.

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[101] Larson defined accretions as follows:

"An accretion is a situation where the state line flow in the alternate condition – that is, the alternate institutional condition – is higher than the state line flow in the original condition. So there is an increase in the state line flow as a result of this for that particular month, rather than a decrease which would be a depletion." RT Vol. 128 at 6.

Kansas properly seeks protection against an averaging process that would allow depletions to be offset by later accretions that might not be usable because of amount or timing, or might simply come too late to compensate for earlier injury. Article IV-D of the compact addresses not only quantity but also protects the "availability for use" of Stateline flows. But this is not to say that accretions should always be disregarded. In its Reply Brief at 81, Kansas takes the view that it would be inconsistent with Article IV-D to offset accretions because the compact prohibits depletions only. I do not agree with that interpretation of the compact. The compact was never meant to regulate the myriad of activities in Colorado that can both add to or subtract from the water in the Arkansas River, except to require that the net result of such development will not materially reduce the usable flow at the Stateline.

Whether accretions may appropriately be considered as an offset to depletions requires an analysis of each particular situation. RT Vol. 113 at 15-17. However, there was little effort by the parties to see if any individual accretions were in fact usable and could properly reduce depletions. In part, this may have been due to the fact that the impact from pumping was not much different whether depletions alone were considered, or depletions less accretions. Colo. Exh. 1012; RT Vol. 138 at 80. The Colorado water budget analysis showed only small accretions due to pumping. Kan. Exh. 643.

Accretions produced by the revised H-I model result primarily from the logic used in reservoir operations. RT Vol. 111 at 149; RT Vol. 138 at 73, 78. The timing of both depletions and accretions is an artifact of the modeling process,[102] and is not likely to be exactly replicated in actual operations. For this reason alone, it may be extremely difficult to determine whether accretions calculated by a model should be used to reduce depletions. However, that issue needs to be examined.

G. Conclusions.

Based upon all of the evidence in the case, including the Colorado water budget analysis discussed in Section XX, and regardless of which burden of proof applies, I have no difficulty in concluding that postcompact pumping in Colorado has caused material depletions of the usable Stateline flows of the Arkansas River, in violation of the Arkansas River Compact. The total amount of such depletions over the 1950-85 period is much more difficult to determine. If my conclusion on liability is confirmed by the Supreme Court, then, to refine the total amount of depletions, additional evidence will be required during the remedies phase of the trial.

This conclusion relates only to postcompact pumping in Colorado, and not to the Winter Water Storage Program. The impact, if any, of that program is discussed in Section XXII hereof.

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[102] Releases from John Martin Reservoir, for example, are in part dependent upon the numbers used in the model to simulate monthly demand by Kansas. These numbers reflect some averaging and calibration techniques, and do not vary in the short term with weather or crop conditions. RT Vol. 111 at 23-39, 145-47; RT Vol. 112 at 49-50; RT Vol. 138 at 73-74, 78.

SECTION XX

COLORADO WATER BUDGET ANALYSIS

Counsel for Colorado described its water budget analysis as being at once "both simpler and more complex than the hydrologic-institutional model." RT Vol. 59 at 27. While Colorado generally referred to its approach as a water budget, it actually embraces four integrated models. It involves an analysis of the river system in two separate reaches. The portion between Pueblo and John Martin Reservoir was identified as Reach 3, while the downstream area between John Martin Reservoir and the Stateline comprised Reach 4. For each of these reaches, Colorado developed a separate groundwater model and a water budget model. The data used in Colorado's water budget, and the results, are found in Colorado Exhibit 4*.

Overall, Helton testified that "there has been some impact on state line flows as a result of post-compact pumping." RT Vol. 115 at 62. Above John Martin Reservoir, the impacts in his opinion have been largely offset by the return flows from transmountain imports. *Id.* Below John Martin Reservoir, Helton believes that the impacts have resulted largely from wells constructed downstream of the Buffalo Canal headgate. *Id.*

The groundwater models were used to estimate return flows and the effects of groundwater pumping. Groundwater withdrawals and recharge to the groundwater system were estimated using the water budgets, and that information was passed to the groundwater models. The groundwater models then calculated stream-aquifer interactions, drain flows and changes in groundwater storage. These data were then passed back to the water budget models to calculate ungaged tributary inflows.

The Colorado water budget analysis cannot be directly compared with the results of the revised H-I model. RT Vol. 127 at 115-16. Colorado does not predict streamflows and diversions as Kansas does. Instead, the Colorado process starts with actual historical diversions, and then estimates the increase or decrease in streamflow that would have occurred under different hydrological or institutional conditions. The river gains or losses are then allocated according to historic demands and rights. The unknown in the Colorado analysis, that is, the residual for which the process solves, is the amount of ungaged tributary inflow. RT Vol. 101 at 33, 43.

The groundwater models are calibrated against well levels, but since the process does not produce predicted streamflows, the final results cannot be compared against measured flow of the river or the output of the revised H-I model. RT Vol. 127 at 70. Nonetheless, Larson did not believe that the differences between the Colorado and Kansas approaches were necessarily significant. RT Vol. 99 at 60-61.

From the outset, Colorado emphasized the need for a more complete and accurate data base for use in the modeling effort. Colorado Attorney General Gale C. Norton, in her opening statement, outlined the data deficiencies and the state's determination to obtain the best and most accurate data possible.[103] RT Vol. 59 at 9. She

[103] Larson also testified to the lack of historical data, namely, pumping records, the distribution of pumping,

pointed out that the state government had a responsibility to all Colorado water users, some of whom were also being injured if the allegations of Kansas were correct. *Id.* at 10. In order to obtain an adequate scientific basis for decisions, she said: "We chose to place our resources in an effort to develop the best data that we could." *Id.* at 10.

Colorado did, indeed, spend much effort in collecting new data, and verifying and sometimes correcting old data. Much of this work is discussed in the testimony of Hal Simpson, then the Deputy State Engineer, Division of Water Resources.[104] RT Vols. 67, 68. The basic data collection effort included aerial photos and field studies to determine irrigated acreage; a field inventory of wells; reviewing and revising diversion data; tabulating water rights; locating ditch laterals and drains on maps; and making certain flow measurements. Toward the end of the trial, Colorado produced a number of useful exhibits comparing the data sets used by Colorado in its water budget analysis and the data used by Kansas in the revised H-I model.

A. Common Data.

Helton was the expert who testified to this series of comparative data exhibits. RT Vol. 113 at 100 *et seq.*; RT Vol. 114. In his opinion, the differences between the states

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ungaged tributary inflow, off-stream reservoir storage, winter consumption and evaporation, and use by phreatophytes. RT Vol. 127 at 63-65.

[104] Mr. Simpson is now the Colorado State Engineer.

were not significant with respect to the following data sets: upstream inflow, Colo. Exh. 831; transmountain deliveries, Colo. Exh. 846;[105] winter storage accruals in Pueblo Reservoir, Colo. Exh. 847; winter storage releases from Pueblo Reservoir, Colo. Exh. 848; rainfall comparisons, Colo. Exh. 855; assignment of climatic stations for rainfall and evapotranspiration ("ET"), Colo. Exhs. 856, 857; crop data, Colo. Exh. 859; and crop water requirements, Colo. Exh. 860.

B. Significant Differences in the Data Sets Employed by the Two States.

According to Helton there were significant differences in the data sets used by the two states in other areas: precompact pumping allowance, Colo. Exh. 993; total pumping, Colo. Exhs. 822, 852; ungaged tributary inflow, Colo. Exh. 837; certain annual diversions, Colo. Exhs. 838, 839; crop consumptive use, Colo. Exh. 862; and consumptive use by phreatophytes, Colo. Exh. 864.

My analysis of the pumping data appears in Sections XV and XVI and is not further discussed here. Some of the data disputes over the Winter Water Storage Program are also included elsewhere in Section XXII. Other basic data issues, however, are covered in the subsections that follow. Kansas' experts were of the view that for purposes of modeling Stateline depletions, the important

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[105] For the 1950-85 period, the revised H-I model used a total of 2,176,006 acre-feet of total transmountain imports. Colorado's slightly revised total was 2,023,576 acre-feet. RT Vol. 114 at 7-13.

differences in data relate to pumping and to ungaged tributary inflow. RT Vol. 99 at 118-19.

C. Irrigated Acreage in Colorado.

Both states calculated irrigated acreage from aerial photographs. Colorado relied on ASCS[106] photos from 1947, 1953-54, 1962-64 and 1970, and on 1985 photos taken on a special flight arranged by the Colorado state engineer. Colorado assumed linear trends between the various sets of photos, and results were also compared with a 1939 study by the Colorado Water Conservation Board. Moreover, Colorado conducted a land use study in 1985 to provide "ground truth" for the interpretation of the aerial photos. RT Vol. 59 at 19.

Kansas based its calculations on two ASCS sets of aerial photos, using 1957 photos for the 1950-69 period, and 1980 photos for 1970-85. It had little practical access for making detailed field studies. Nonetheless, the Colorado and Kansas figures for average irrigated acreage in Colorado over the 1950-85 period are remarkably close. Colo. Exhs. 827, 828, 829, 830. The amount was approximately 319,000 acres, which compares to a total of approximately 317,000 acres at the time the compact was made. Colo. Exhs. 829, 830.

Colorado argues, however, that Kansas did not make the same detailed analysis which Colorado had made in locating the amount of acreage served by each canal

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[106] Agricultural Stabilization and Conservation Service.

system. As a result, Colorado claims there were inaccuracies in the amounts of irrigated acreage assigned to individual ditch systems used in the H-I model. RT Vol. 113 at 101-110. Colorado attributes part of the H-I model's problems to this allocation, and to the assumption that greater accuracy was not required in determining where water was used because the river basin could be modeled as a linear system.

Both states show a small decline in total irrigated acreage when comparing 1950 with 1985. For Kansas, the reduction is a little over 3,000 acres. For Colorado, the amount is about 14,000 acres, most of which reflects a sharp decline between the 1980 ASCS photo results and Colorado's own 1985 flight results. Colorado says the reduction is due primarily to the conversion of certain irrigation water rights to municipal use. Colo. Closing Well Br. at 17-18. The municipal use of Arkansas River water is relatively small, and was not an issue in this case. However, aside from any change from irrigation to municipal use, a reduction in irrigated acreage does not necessarily mean a reduction in the use of water. The system is water short. Agriculture in Colorado needs more water than the river generally provides. Pumping has partially met that need and has increased the overall use of water in Colorado. Comparing early postcompact years (1950-65) with the later period (1966-85), total supply has increased in Reach 3 from 3.21 acre-feet per acre to 3.69 acre-feet. And in Reach 4, the increase has gone from 2.15 to 2.58 acre-feet per acre. Computed from Colo. Exh. 4*, Tables 5.5 and 5.12, Col. 10.

Looking at the two reaches of the river, both states show that a reduction in irrigated acreage has occurred in

Reach 3, upstream from John Martin Reservoir. On the other hand, in Reach 4 between John Martin Reservoir and the Stateline, irrigated acreage has increased between 10,000 and 12,000 acres since 1950. Colo. Exhs. 827-30. Increased water use in Reach 4, of course, has the most direct impact on Stateline flows. Total water requirements (April through October) for irrigating approximately 319,000 acres in both reaches were estimated by Colorado to be 820,000 acre-feet and by Kansas to be 798,824 acre-feet. Colo. Exh. 860.

D. Surface Diversions in Colorado.

Diversions from the surface flow of the Arkansas River by the various canal companies in Colorado have long been measured and the results published. These data, however, were carefully reviewed by Colorado for purposes of this action and certain corrections were made. I believe they now represent the most accurate information available. Kansas continued to use the diversion figures maintained and published by the Arkansas River Compact Administration, but its results are nonetheless quite similar to those of Colorado. Average annual diversions for the 1950-85 period, as computed by Colorado, amounted to 884,881 acre-feet. The Kansas data, collected by Spronk Water Engineers, averaged 887,612 acre-feet. Colo. Exhs. 838, 839.

Kansas, however, did not use these diversion figures as input into the H-I model. Instead, it designed the model to *predict* such diversions. This was to allow diversions to vary according to changing amounts of assumed pumping. Actual measurements of diversions were then used to check the accuracy of the model's predictions. Historic diversions, as calculated by the revised H-I model for 1950-85 averaged 923,415 acre-feet annually. *Id.* To some extent, these figures bear out Schroeder's conclusion that the H-I model has a chronic problem of overpredicting diversions.

The Colorado water budget used actual diversion figures, but then changed them in accordance with estimated gains or losses in river flow based upon changes in pumping. Thus, the Colorado analysis dealt with changes in flow rather than with the total amount of flow. This approach has the advantage, according to Colorado experts, of confining any model error to a smaller portion of the total river flow. However, it also has the disadvantage of not being able to test the water budget results against Stateline flows.

Diversions have increased somewhat in the postcompact years, although transmountain imports have also increased. During the compact negotiations, the engineering committee submitted a report showing that diversions in Colorado over the 1908-42 period had averaged 857,200 acre-feet annually. Jt. Exh. 5 at 20. Based on Colorado's figures, the average for 1950-85 was 884,881 acre-feet. Colo. Exhs. 838, 839. However, the 1950-85 average includes diversions of imported water while the 1908-42 calculation does not. Without consideration of the diversion of transmountain imports, there has been a slight decrease in diversions of about 28,000 acre-feet annually. Kansas argues that the decline is more than offset by increased pumping.

E. Inflow from the Purgatoire River.

The Purgatoire is the largest tributary of the Arkansas River in Colorado and there was some suggestion that the decline in Stateline flows was due in part to reduced inflow from the Purgatoire. Both states relied for their measurements upon the USGS gage on the Purgatoire near Las Animas. For the 1950-85 period, inflow to the Arkansas River averaged 61,659 acre-feet annually. Colo. Exh. 836; Kan. Exh. 50*. Comparing early and late compact years, the 1950-64 period averaged 65,301 acre-feet per year, while the 1965-85 period averaged 48,447 acre-feet.[107] Thus, the measurements show a small decrease in flow, although the early 1950-64 average is heavily influenced by flood flows in a single year, namely, 1955; total flows in 1955 amounted to 232,368 acre-feet. It is also important to note that the models of both states took the Purgatoire flows into account, and isolated Stateline depletions caused by pumping and the WWSP only.

F. Ungaged Tributary Inflow.

Estimating the inflow from ungaged tributaries to the Arkansas River proved to be a difficult problem for all of the experts. Some tributaries have flow measurements for certain years only, but others have no flow records at all. Jt. Exh. 94 at 9-13. One of Colorado's experts, Dr. Young

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[107] This comparison omits the flood year of 1965, during which flows were 271,256 acre-feet.

Yoon,[108] at first attempted to apply a rainfall-runoff model to estimate ungaged tributary inflow, but concluded that the rainfall data were insufficient for this approach. RT Vol. 73 at 46. A rainfall-runoff model depends upon developing a reliable correlation between precipitation and the resulting runoff. Here, Dr. Yoon concluded, the scarcity of rainfall stations[109] and the erratic nature of the precipitation[110] precluded such a model. RT Vol. 101 at 36. Colorado ultimately made ungaged tributary inflow the residual in its entire water budget analysis, and used that process to solve for such flows. For the 1950-85 period, Colorado calculated that the total ungaged tributary inflow in Reaches 3 and 4 averaged 182,865 acre-feet per year as corrected. Colo. Exh. 837; Colo. Exh. 4*, A.1 and B.1, Col. 6.

The Kansas estimate was substantially lower, namely, 86,571 acre-feet. The Kansas figures came from Durbin's rainfall-runoff model which developed a relationship between precipitation and runoff derived from watersheds with some gaged streamflow records. RT Vol. 42 at 65. Such annual flows were then processed by a special version of the H-I model (sometimes referred to as "GLOBAL") in order to determine monthly values and to match observed streamflows. RT Vol. 42 at 56-58, 72. This

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[108] His qualifications are found in Colo. Exh. 671. His initial assignment was to develop water budgets for the two reaches. RT Vol. 101 at 79.

[109] There were 16 rain gage stations located throughout the tributary basin areas. RT Vol. 101 at 64, 74.

[110] Dr. Yoon testified that most of the rain came in the form of thunderstorms. RT Vol. 73 at 78-79.

monthly adjustment step was dropped by Kansas' replacement experts. Larson testified that it was not necessary, and that the rainfall-runoff model results could be appropriately inserted as direct input into the revised H-I model since overall the model achieved sufficient calibration based on streamflow and diversion data without further adjustments. RT Vol. 100 at 79.

Colorado claims that the Kansas methodology[111] underestimates ungaged tributary inflow, and Larson testified that this might be true, although no amounts were given. RT Vol. 100 at 79-80. However, there is also persuasive evidence that the Colorado figures for ungaged tributary inflow may indicate problems with the Colorado models, and may be too high.

The Colorado water budget analysis accumulates in the results calculated for ungaged tributary inflow any model errors that occur. RT Vol. 127 at 105. And there is indication of such errors. RT Vol. 101 at 75-77. The Colorado models produced what the engineers called "negative" tributary flows, that is, according to the models water sometimes flowed uphill into the tributaries rather than toward the Arkansas River. RT Vol. 101 at 67-69. This meant that the models were calculating too much water. The excess could not be added to the Arkansas River because those downstream flows are specified and fixed in the Colorado models. So, as Larson put it, "you have to

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[111] The parameters used in Durbin's rainfall-runoff model were derived from an analysis of Horse Creek data, and there was uncontroverted evidence that the gage measurements on this creek may have been affected by upstream diversions. RT Vol. 100 at 80.

send water up the tributaries in order to balance the water budget." RT Vol. 127 at 106. Negative flows occurred in Reach 4 in some 70 to 80 months during the 1950-85 period. RT Vol. 101 at 68-69. While Colorado always emphasized the soundness of the data used in its water budget analysis, the models also included some 27 parameters or coefficients that were not field measured, but were estimated on the basis of local experience, judgment or handbooks. RT Vol. 102 at 14. To Larson, the negative tributary flows indicated potential problems and that adjustments were needed within the water budget portion of the Colorado analysis. RT 127 at 107, 112.

Larson also plotted actual measured flows from Big Sandy Creek for the years 1968-82 against the amounts of flow calculated by the Colorado water budget. Kan. Exh. 694. The Big Sandy watershed includes about 60% of the tributary areas in Reach 4. RT Vol. 127 at 110. The calculated flows for these years are substantially in excess of the measured flows for the same years. Larson concluded overall that there were indications that Colorado's ungaged tributary inflows "may be too high." RT Vol. 127 at 113.

Dr. Yoon initially indicated that ungaged tributary inflow declined during the 1970s. On cross-examination, however, he acknowledged that if the single month of June, 1965 were removed from the comparison, the decline would be hydrologically insignificant. RT Vol. 102 at 45, 48, 52-53.

Mr. Durbin did not believe that close accuracy in estimating ungaged tributary inflow was critical. Since such flow represented only a small portion of total flow, and since the same figures were used in both runs of each pair of comparative runs of the H-I model, he testified that any error would have little impact on the use to which the model was being put. RT Vol. 46 at 97-98, 117; RT Vol. 47 at 37. Colorado, however, points out that the adjusted tributary inflows were used in the H-I model to calibrate the values of nonbeneficial consumption of applied surface water and tailwater runoff. In turn, these factors were used in the calibration of the WANT factors to predict diversions.

It is not possible to determine with accuracy what the ungaged tributary inflows may have been over the years. The best estimate is likely to fall somewhere between the amounts calculated by the two states. However, it does not appear that this factor is critical to the revised H-I model. On rebuttal, Larson produced a series of "sensitivity" runs. Kan. Exh. 691. In one of these runs he used ungaged tributary inflow values that were more like those derived by Colorado. The result was to decrease depletions, but not by a major amount. *Id.*, Comparison 5. This change put the model out of calibration. When Larson adjusted the noncrop ET coefficients in the model in order to bring it back into approximate calibration, the depletions were essentially the same as those originally shown by the revised H-I model. *Id.*, Comparison 6; Kan. Exh. 111***; RT Vol. 127 at 91-92.

G. Consumptive Use by Phreatophytes.

The experts for both states agreed that the consumptive use of Arkansas River water by phreatophytes[112] had increased over the postcompact years. The three major upstream dams and reservoirs have reduced the high flood flows that used to scour the river channel. Undoubtedly, the increased use of river water by natural vegetation in Colorado has had some impact on Stateline flows, but Kansas makes no claim based on any such depletions.

The Kansas expert witness was Dr. David P. Groeneveld, a consulting plant ecologist who specializes in the study of phreatophytes.[113] RT Vol. 24 at 83, 90-91. Colorado used Robert A. Longenbaugh, an assistant state engineer, Colorado Division of Water Resources, and former associate professor at Colorado State University. Mr. Longenbaugh has testified as an expert witness on many previous occasions but never before had qualified as an expert on phreatophytes. RT Vol. 62 at 81-82. His experience in mapping and determining the consumptive use of phreatophytes did appear to be somewhat limited.[114]

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[112] Defined as plants that receive all or part of their water from groundwater. RT Vol. 24 at 116. More commonly, phreatophytes are thought of as natural riparian vegetation. Along the Arkansas River "woody" phreatophytes include salt cedars, cottonwoods and willows. "Herbaceous" phreatophytes include kochia, saltgrass, cattails and other grasses.

[113] His curriculum vitae is Kansas Exhibit 487, and includes considerable experience in using aerial photography to map vegetation.

[114] His qualifications appear in Colorado Exhibit 664.

Both experts relied extensively on two prior reports, one published by Bittinger and Stringham in 1963,[115] and one by Lindauer and Ward in 1968.[116] RT Vol. 24 at 106; RT Vol. 62 at 109, 117. Bittinger estimated the consumptive use of phreatophytes from Pueblo to the Stateline to be about 65,900 acre-feet annually, with an accuracy within 20%, plus or minus. Jt. Exh. 61, Table 9 at 20; RT Vol. 26 at 28, 60. Lindauer mapped the vegetative cover but did not actually estimate consumptive use.

Dr. Groeneveld attempted to determine what changes, if any, had occurred since the Bittinger report. RT Vol. 24 at 136. He concluded that use by phreatophytes had increased by about 14,000 acre-feet annually over Bittinger's 1957 estimate, reaching a total of 79,424 acre-feet in 1983. Kan. Exh. 526. He agreed that there was also a range of error in this estimate and that the increased use might be as low as 10,000 or as high as 19,000 acre-feet. RT Vol. 26 at 81. Most likely, however, he thought the range was between 12,000 and 16,000 acre-feet. *Id.*

Groeneveld employed accepted techniques comparing the 1957 aerial photos used by Bittinger with a set of 1983 color, infrared aerial photographs. Transects across the river were established at 80 locations between Pueblo and the Stateline. (Bittinger had used only 18.) RT Vol. 24 at 121; RT Vol. 26 at 41. The type of vegetation and the percentage of ground covered by such vegetation were determined along each of these transects. In this process,

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[115] Jt. Exh. 61.

[116] Jt. Exh. 62.

Groeneveld used a stereoscope which magnifies depth perception and provides three-dimensional viewing of the aerial photography. Evapotranspiration rates ("ET"), which are available in the literature for each type of vegetation, were then applied to the percent of coverage and area in order to reach an acre-feet figure for consumptive use. RT Vol. 24 at 127-28. The Kansas study of phreatophytes was limited to the flood plain of the river.

A recent report[117] of the United States Department of Agriculture, done in cooperation with the Colorado Water Conservation Board, produced an estimate fairly close to Groeneveld's figure. Jt. Exh. 108. The report separately estimates consumptive use by phreatophytes in five reaches of the river between Pueblo and the Stateline, giving a total of 72,900 acre-feet. *Id*, Table A-14 at A-36.

Mr. Longenbaugh's estimate for the increase in consumptive use between 1957 and 1983 was 31,718 acre-feet compared to Groeneveld's estimate of 14,000. Colo. Exh. 786. However, Longenbaugh's initial base from which he calculated the increase was considerably higher. As a result, Longenbaugh estimated that consumptive use by phreatophytes averaged 123,876 acre-feet annually over 1950-85. Colo. Exh. 864. The comparable Kansas figure was 70,580. *Id*. While Longenbaugh did not testify to a specific range of error in his estimates, there is evidence to indicate that his figures were less reliable than those developed by Kansas.

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[117] The study was authorized in 1979, but the report does not bear a date. Colorado's counsel, however, believes that it was published in 1986. RT Vol. 63 at 22.

To begin with, Longenbaugh used George Moravec's[118] 1985 black and white aerial photos and mylar overlays to determine the boundaries of the area where phreatophytes were located, and the amount of acreage involved. RT Vol. 62 at 107; RT 63 at 81. Moravec determined that in 1985 there were 29,519 acres of woody phreatophytes between Pueblo and the Stateline, and 13,026 acres of herbaceous phreatophytes. Colo. Exh. 487, Table 1 at 8; RT Vol. 62 at 159. This acreage was also confined to the floodplain of the river. RT Vol. 61 at 68.

Moravec testified that he established his boundaries in the same manner as Bittinger. RT Vol. 61 at 71, 81-82. However, Bittinger did not map any boundaries for herbaceous phreatophytes. RT Vol. 63 at 105, 116. Nor did Lindauer. *Id.*; RT Vol. 64 at 94; Jt. Exhs. 61, 62. Indeed, Moravec provided no good explanation as to how the boundaries for herbaceous phreatophytes were established, and how he distinguished herbaceous phreatophytes from the nonphreatophytic cover in the surrounding upland areas. Some of his herbaceous acreage extended a half mile or more from the river, and included areas where the groundwater levels appeared to be too far below ground surface to supply any herbaceous phreatophytes. RT Vol. 64 at 41-45; RT Vol. 63 at 114; Colo. Exh. 685.

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[118] Mr. Moravec is a hydrogeologist with the Colorado Department of Health, and previously was with the Colorado Division of Water Resources. He has had practical experience with aerial photos and in using them to map irrigated acreage and vegetation, but no formal education in plant ecology. His qualifications are found in Colorado Exhibit 666.

Accepting the Moravec boundaries and acreage, however, Longenbaugh then assumed that this total amount of acreage, for both woody and herbaceous phreatophytes, had remained constant throughout all years since 1950. RT Vol. 63 at 138. To develop the herbaceous acreage for earlier years, he increased such acreage backwards in time by taking the difference between the amount of total acreage and the amount assigned in each of those earlier years to woody phreatophytes. *Id.* at 106, 137. I find no support in the evidence for these assumptions. They result in much greater phreatophytic acreage than the well accepted Bittinger and Lindauer reports calculated, and account for much of the higher consumptive use figures developed by Colorado. To determine the consumptive use of herbaceous phreatophytes, Longenbaugh also assumed that the cover was 100 percent. *Id.* at 181.

The actual consumptive use for herbaceous phreatophytes in 1985 was calculated to be 3.91 acre-feet per acre in Reach 3 above John Martin Reservoir, and 3.58 acre-feet downstream in Reach 4. Colo. Exh. 438*. These amounts were based upon a curve developed by Longenbaugh that relates the amount of consumptive use by herbaceous phreatophytes to the depth to groundwater. Colo. Exh. 679*. This curve shows that groundwater must be within one foot of the surface of the ground for herbaceous phreatophytes to consume 3.91 or 3.58 acre-feet per acre. RT Vol. 64 at 36-37. Colorado's groundwater models calculated these sensitive depths to water and applied the curve in Colorado Exhibit 679* in order to arrive at the consumptive use figures. RT Vol. 63 at 111-12, 136; RT Vol. 64 at 45. Longenbaugh expressed confidence that the groundwater models provided the "right answers." RT Vol. 64 at 45.

However, actual well measurements, not model output, indicated otherwise. Of 27 wells located along and near the river, only four showed water levels within a foot of the ground surface. Colo. Exh. 685. Longenbaugh attempted to justify the 3.91 and 3.58 consumptive use figures on the ground that they were averages of some high areas of use[119] and other areas where the consumption was zero. RT Vol. 64 at 54-55. However, Colorado had no quantitative data in the areas of such high use vegetation, and to acknowledge areas of no consumptive use would indicate that Moravec's boundaries and acreage were incorrect.

Other questions could be raised about the Colorado estimates,[120] but perhaps this is sufficient. Certainly the water use by native vegetation over 150 miles of river and for a 36 year period cannot be determined with precision. However, it is not clear how significant the differences between the estimates of the states are for modeling purposes. This was not an important issue in the post-trial briefs of the parties. Nonetheless, to the extent that

[119] For example, cattails at 5.7 acre-feet per acre.

[120] For example, the percent of cover used in the calculations for woody phreatophytes was largely the result of subjective judgment rather than any scientific methodology. RT Vol. 63 at 80, 87-88, 142-44; RT Vol. 64 at 85. Longenbaugh's percentage substantially increased the earlier Bittinger and Lindauer estimates, and contributed heavily to his final consumptive use estimates. His approach can be contrasted with Groeneveld's direct analysis of 80 representative transects of 1983 aerial color photos.

consumptive use by phreatophytes can significantly affect the modeling of Stateline depletions, I find that the Kansas estimates are most likely to reflect actual use.

H. Results of Colorado Water Budget Analysis.

The impacts of postcompact pumping in Colorado on Stateline flows as derived from the Colorado water budget analysis can be found in Colorado Exhibit 135*, p. 6.1, col. 16. The results for the 1950-85 period are not immediately apparent since the exhibit does not provide totals. However, Helton confirmed that total depletions to Stateline flows for the full 1950-85 period amount to 582,696 acre-feet. RT Vol. 134 at 13; RT Vol. 117 at 75, 102.

These results are derived from what Colorado called its "What-if 2" scenario. In that analysis, Colorado made one model run based on historical conditions. In that run total pumping averaged 145,199 acre-feet annually, which is the amount estimated by Colorado. Colo. Exh. 135* at 1.1. Colorado then paired the historical run with a second model run in which pumping levels were held to the so-called precompact amounts. The precompact allowance averaged 49,275 acre-feet annually. Thus, the What-if 2 comparison registered the impact on Stateline flows of the difference between Colorado's view of allowable precompact pumping and later total pumping, namely, an average of 95,925 acre-feet annually for the 1950-85 period. RT Vol. 133 at 53-54. This is comparable to an annual average of 150,394 acre-feet which Kansas used in determining Stateline depletions from postcompact pumping. Kan. Exh. 731.

The Colorado figure of 582,696 represents depletions caused by postcompact pumping in Colorado in terms of total Stateline flows, not usable flows. RT Vol. 134 at 14. Colorado presented no evidence of its own on depletions of usable flow after the year 1969.[121] Colo. Exh. 135*, pages 7.1-7.3. According to Helton, there was not an adequate basis for making a determination of usable flow in the absence of records from the gaging station at Garden City. RT Vol. 134 at 14; RT Vol. 117 at 101-02. From 1970 through 1986 the gage was maintained only for flood flows, although continuous recorder charts remained in place which reflected water levels at the gage. Kansas later used these data to estimate daily flows past Garden City; any such flows were considered by Kansas to be unusable.

While Colorado introduced no evidence reducing the 582,696 acre-feet of depletions of total flow to depletions of usable flow, Kansas did make such an effort. Larson testified that this amount translated into 411,000 acre-feet of depletions of usable flow. RT Vol. 127 at 94. In making this calculation, Larson applied the Spronk method of determining usable flow. The validity of this approach is discussed in Section XXI.

Colorado's depletion figure of 582,696 represents Stateline depletions which still remain *after* deleting the effect of return flows from transmountain imports. RT Vol. 134 at 14; RT Vol. 115 at 75; Colo. Letter of 8-24-93 at

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[121] Helton did, however, critique the Kansas evidence on usable flows which covered the full 1950-85 period. He also proposed different coefficients if the Kansas methodology were to be used. This subject is covered more fully in Section XXI.

11. Helton testified that the results of the Colorado water budget were reasonable on a monthly basis, more accurate on an annual basis, and "more accurate yet" on a long-term average. RT Vol. 117 at 100.

While Colorado's depletion figure is high because not reduced to usable flows,[122] it is also low in two other respects. First, the assumed amount of postcompact pumping is not sufficient; this issue is treated in Section XV. Second, the Colorado analysis offsets what has been termed the "clear water effects." The construction of Pueblo Dam reduced the amount of silt in the river. In turn, this increased seepage in the upstream canals and laterals, particularly in the Bessemer system. Helton testified that farmers were thus required to pump more water in order to obtain the same total irrigation supply. RT Vol. 134 at 16-17.

In Colorado's What-if 2 run, therefore, seepage losses were allowed to increase, thereby resulting in lower calculated depletions at the Stateline. *Id.*, at 22. In essence, Helton treated the pumping increment which offsets these increased seepage losses as part of Colorado's historic water supply, rather than as postcompact well pumping. While the impact is apparently small, I do not

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[122] Colorado maintains that the figure is also high for other reasons. In its "What-if 2" analysis Colorado did not "reoperate" John Martin Reservoir. Had it done so, Colorado states, the depletion amount would have "declined substantially." RT Vol. 142 at 103. Helton also testified that the Colorado analysis did not consider that some Colorado ditches would have exercised their surface rights more frequently if supplemental wells were not available. RT Vol. 117 at 131-33. However, no specific or quantitative evidence was submitted on these points.

believe this is proper. RT Vol. 117 at 70-71. There is no question about the substantial benefits accruing to Colorado from the construction of Pueblo Dam. *Id.*, at 74. Sediment control for the benefit of upstream Colorado ditches was one of the purposes of Pueblo Reservoir. Jt. Exh. 166 at 23, 25, 26. Any burdens from the project must also be accepted.

In an effort to compare the revised H-I model results with those derived from Colorado's water budget, Kansas made one run of its model using Colorado's figures for pumping and an approximation of Colorado's What-if 2 scenario.[123] For the same amount of postcompact pumping, Colorado's own What-if 2 analysis calculated total Stateline depletions of 583,000 acre-feet for 1950-85, while the H-I model run indicated depletions of only 395,000 acre-feet. Kan. Exh. 642; RT Vol. 127 at 93. Kansas points to this comparison to show, despite Colorado's many criticisms of the H-I model, that the revised model actually produces smaller Stateline depletions per acre-foot of pumping than Colorado's own water budget. Colorado does not deny this fact.[124] Rather, it attempts to deflect

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[123] In its What-if 2 scenario, Colorado used the figure of 3,453,000 acre-feet as the difference between its claimed precompact allowance and total pumping for the 1950-85 period. Kansas originally used 5,414,000 acre-feet as its comparable figure on which depletions were based, as shown in Kansas Exhibit 111***. However, in this run of the revised H-I model, Kansas used Colorado's pumping, namely, 3,453,000 acre-feet. Kan. Exh. 642.

[124] "Kansas also asserts that Colorado made many efforts 'to minimize the calculated effects of pumping on the stateline flows.' *Id.* at 74. This assertion has a hollow ring given the fact that the Colorado analysis shows higher depletions than the

the argument, saying that nonetheless the conclusions to be drawn from Colorado's analysis "are very different." Colo. Response Br. at 93.

Colorado refers to Helton's conclusion that transmountain return flows have largely offset the impacts of postcompact pumping above John Martin Reservoir. But this does not explain away depletions at the Stateline of 582,696 after the offset from transmountain flows has been taken into account. Colorado also refers to Helton's conclusion that depletions of Stateline flows were due largely to wells constructed east of the Buffalo headgate after 1965. Again, while this may be useful in any remedy phase of the trial, the location in Colorado of any wrongful pumping, insofar as liability is concerned, does not matter if the result is a compact violation at the Stateline. The cause of the calculated depletions is not in dispute. Both Colorado's What-if 2 scenario and Kansas' H-I model runs were specifically designed to isolate the impacts of postcompact pumping in Colorado on Stateline flows. Colorado's analysis shows that Stateline depletions are equal to 17% of the amount pumped, while the Kansas estimate is only 11.3%. Calculated from Kan. Exh. 642.

Colorado's What-if 2 analysis also carries a column entitled "Potential Impact on Kansas." Colo. Exh. 135*, page 6.1, column 17. This again considers the impact of 3,453,000 acre-feet of postcompact pumping. The column shows an average "potential impact" of 7,755 acre-feet

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results calculated by the H-I Model, as revised [by] the Kansas replacement experts." Colo. Response Br. at 77; see also pages 93-94.

annually for the 1950-85 period, or 279,180 acre-feet for the whole period. It is computed by taking 40% of the change in conservation storage in John Martin Reservoir and adding depletions in Stateline flow from April through October. RT Vol. 134 at 22-23. Depletions occurring from November through March were not included because, according to Helton, those flows "weren't used in Kansas." RT Vol. 115 at 78. Helton testified that these potential impacts were not the same as depletions of usable flow, but would be "further reduced for the times when Kansas did not fully use all of the water that was available there historically." RT Vol. 134 at 23.

I. Colorado's Modifications to the Revised H-I Model.

During the course of the trial, Colorado developed the capability of operating and adjusting the Kansas revised H-I model. Schroeder made a number of changes to the H-I model input and code, including removal of the canal capacity and diversion reduction factors. Colo. Exhs. 1008, 1009. He then attempted to recalibrate the model, and in his opinion achieved a "similar degree of accuracy" to that obtained by Kansas. RT Vol. 138 at 137; RT Vol. 139 at 18; Colo. Exh. 1010. In all, he made some 900 runs, but presented, in Colorado's Exhibits 1011 and 1012, the results of only a limited number of comparisons. RT Vol. 139 at 42. However, he was not prepared to sponsor these results. While he believed that the Stateline depletions shown by his modified H-I model runs were more appropriate than the depletions shown in Kan. Exh.

111***,[125] he still testified that his modified version of the H-I model was "inaccurate, inappropriate, and not a reasonable tool." RT Vol. 139 at 96, 67. None of the results depicted in Colorado Exhibits 1011 and 1012 was an "appropriate quantification," he said. RT Vol. 140 at 97.

Kansas objects strongly to Colorado's modifications of the H-I model, claiming they were "selective." Kan. Answer Br. at 28. However, it seems unnecessary to treat Kansas' criticisms in detail here in view of Schroeder's own testimony that he did not adopt the H-I model results, even with his modifications.

J. Conclusions.

Colorado's own water budget analysis essentially disposes of the issue of liability from pumping, except for possible affirmative defenses. And none of those defenses is asserted as a complete bar to all liability. Laches is raised as to wells constructed prior to 1965, but Colorado's experts have testified to depletions from wells drilled later, below the headgate of the Buffalo Canal, the last canal in the Colorado system. Colorado also asserts that the benefits of the 1980 Operating Plan should offset the depletions caused by wells located below John Martin Reservoir. However, I have already concluded in Section

[125] Schroeder's version of the revised H-I model still showed substantial depletions from pumping. Considering depletions alone, without accretions or adjustment for usable flow or offsetting the return flows from transmountain imports, Stateline depletions were 545,000 acre-feet for the 1950-85 period. This compares with the Kansas estimate of 612,000 acre-feet. Kan. Exh. 742. Both of these estimates used Kansas' figure for postcompact pumping.

XIV that the 1980 Operating Plan was not intended to, and should not, cancel out compact violations. The laches and mitigation arguments made during the consideration of my Draft Report are even more limited.

The Colorado estimate of Stateline depletions caused by postcompact pumping over the 1950-85 period, namely, 582,696 acre-feet, represents depletions of total flow, not of usable flow. However, there is sufficient evidence in the record to conclude that these depletions would still be substantial, even after reducing them to usable flow. Moreover, I have concluded in Section XV that the amount of pumping which Colorado has used to calculate Stateline depletions is low. Colorado excused almost two million acre-feet of pumping from precompact wells, which I have found to be erroneous.

The actual amount of depletions of Stateline flows from postcompact pumping still remains a major issue. If the Court finds there is liability, then additional evidence will be required during the remedy phase of the trial to refine the amount of depletions in accordance with this Report or the Court's directions. The amount of depletions is critical not only for damages, but also in fashioning a remedy for the future. Colorado now has a limited program in place to control pumping, but it has proved to be inadequate to prevent Stateline depletions. It remains to be seen whether modifications in this program can prevent future compact violations or more stringent controls will be required. It bears remembering that the Arkansas River Compact does not preclude pumping in Colorado, but only postcompact pumping (not offset by transmountain imports) that causes material depletions in the usable flow of the Arkansas River at the Stateline.

SECTION XXI

USABLE FLOW

The Arkansas River Compact provides that future development or construction shall not materially deplete Stateline flows "in usable quantity or availability for use to the water users in Colorado and Kansas." There is no definition of usable flow in the compact itself, and virtually no discussion of the concept in the record of compact negotiations.[126] The concept of usable flow first seems to have appeared in the 1943 decision in *Colorado v. Kansas*, 320 U.S. 383 at 396-97. Justice Roberts wrote on behalf of the Court:

> "The Kansas ditches are capable of diverting water only up to 2,000 c.f.s. When the flow is greater the excess cannot be diverted and used. It is admitted that the character of the flow of the river in Colorado is variable from year to year, from season to season, and from day to day, and the main river below Canon City may be almost without water one day, run a flood the next day, and, on the following day, be in practically its original condition. Thus it appears that both in Colorado and in Kansas there may at one time be flood water unavailable for direct diversion and, at another, not enough water to supply the capacity of diversion ditches. *The critical matter is the amount of divertible flow at*

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[126] There is some discussion in the record of the seventeenth and last meeting of the commissioners concerning this portion of Article IV-D, but the focus is on the term "materially" and offers no help on the meaning of usable flows. Jt. Exh. 3 at 17-32 to 17-37.

times when water is most needed for irrigation. Calculations of average annual flow, which include flood flows, are, therefore, not helpful in ascertaining the dependable supply of water usable for irrigation." (Emphasis added.)

Shortly after this Supreme Court decision, C. L. Patterson, then chief engineer for the Colorado Water Conservation Board, offered his plan for the operation of John Martin Reservoir and the administration of water rights along the Arkansas River. This proposal was approved by the Colorado Attorney General and its chief engineer. Jt. Exh. 8 at 33. In that plan, Patterson recommended the following definition of usable flows:

> "Divertible Stateline flows are those at rates less than 2,000 cfs. in summer months (Apr.-Sep.) and less than 800 cfs. in winter months (Oct.-Mar.);
>
> "Usable Stateline flows are those portions of the divertible flows in volumes less than 30,000 A.F. in one summer month and 120,000 A.F. in one summer season, and in volumes less than 10,000 A.F. in one winter month and 40,000 A.F. in one winter season; and,
>
> "All Stateline flows in excess of said rates and volume are considered undivertible and unusable in Kansas." Jt. Exh. 8 at 23-24.

During the course of the trial, Kansas experts applied this Patterson definition to the total depletions of Stateline flow. The result produced substantially higher quantities of usable flow than any of the approaches used and recommended by the Kansas experts.[127] Kan. Exhs. 646, 648, 683.

A. The Durbin Approach.

Mr. Durbin began to analyze the usable flow issue by first plotting actual diversions in Kansas during the irrigation season against actual Stateline flows. Kan. Exh. 127. He did this for April through October of each year during 1951-85. Through this process, he developed a relationship between diversions and Stateline flows. RT Vol. 45 at 103. These data showed that river flows over 40,000 acre-feet per month were not diverted; moreover, they showed that the April-October diversions would not increase above approximately 30,000 acre-feet per month, regardless of the amount of river flow. *Id.* at 108. On average, Durbin concluded that about 78% of the Stateline flows during the summer were diverted. *Id.* at 109. Flows above 40,000 acre-feet per month during April-October, or above 140,000 acre-feet in total for the whole period, were considered by Durbin not to be usable. *Id.* at 113.

Durbin went through the same process for the winter months of November through March for the period 1951-85. Kan. Exh. 127B. On average, Durbin concluded that 24% of the winter flow was diverted, subject to a cap

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[127] For the April-October period, the Patterson formula indicates that 92% of the Stateline flows would have been used; Spronk's comparable estimate is 66%. For the November-March period, the respective estimates are 85% and 42%. RT Vol. 89 at 63.

of 7,500 acre-feet per month, and to a seasonal cap of 40,000 acre-feet. RT Vol. 45 at 111-12.

Finally, Durbin developed a relationship between Stateline flows and the amount of river flow percolating underground as groundwater recharge. Kan. Exh. 128. Durbin testified that between the Stateline and the Bear Creek Fault zone the river alluvium is very much like the valley fill alluvium upstream in Colorado, and is underlain and bordered by essentially nonwaterbearing rock. RT Vol. 45 at 96. In this reach of the river he said that groundwater recharge was minor, and recharge was not included in his calculations. *Id.* at 97. Downstream from the fault zone the river alluvium is underlain by the Ogallala formation. Between the fault and the Garden City gage, Durbin testified that part of the river flow percolates downward and laterally into the Ogallala formation. *Id.* at 97. For his groundwater analysis, Durbin used the period from 1925 to 1940. He calculated recharge during these years by taking the flows at the Syracuse gage, and subtracting downstream diversions and any flow past the Garden City gage. The balance, he said, went to groundwater recharge. *Id.* 115-17. On average, he concluded that 15% of the Stateline flows were used for groundwater recharge. *Id.* at 116.

B. The Larson Modifications.

As part of Kansas' replacement case, Larson reviewed the Durbin exhibits on usable flow. He prepared certain revised exhibits, following Durbin's concept but with some minor corrections in data. He also eliminated certain high flow months from the calculations, and lengthened the historic period of record used to determine groundwater recharge. Kan. Exhs. 127**, 127A**, 127B**, 128**; RT Vol. 99 at 127-29, 133-36.

As a result, Larson modified Durbin's coefficients, using 72% for the summer irrigation months and 25% for the winter months. RT Vol. 100 at 11. Larson pointed out that Kansas farmers sometimes diverted all of the winter flows available and at other times no winter flows were diverted. On average, however, 25% of Stateline flows were diverted for use during the winter months. RT Vol. 99 at 136. Larson also reduced the percentage of Stateline flows going to groundwater recharge from 15% to 9.9%. RT Vol. 100 at 11.

In calculating groundwater recharge, Larson used the period of 1925 to 1948, excluding the flood year of 1942. RT Vol. 99 at 137. He used the same methodology as Durbin, namely, taking the annual flow at the Syracuse gage, and then subtracting the annual flow at the Garden City gage as well as the diversions from the various Kansas ditches between them. *Id.* at 138. The balance constituted average net groundwater recharge. *Id.* Larson testified that he selected these early years before the compact was signed so that any change in recharge that might have occurred after the compact would not be part of the analysis. *Id.* at 140.

Later in this section, the method devised by Spronk for determining usable flow is described. Larson thought that the Spronk methodology was better than the Durbin approach because it applies a usable flow factor for each month, based on a daily analysis, as opposed to a long-term average value. *Id.* at 142.

C. The Helton Approach.

Colorado's evidence on usable flow was presented through Helton. In his analysis, he examined the Stateline flows, the diversions by the Kansas ditches, gains and losses in the river in Kansas between the Stateline and Garden City, and the flows passing Garden City on a monthly basis. RT Vol. 86 at 41-43; Colo. Exh. 238*. Using Colorado's analysis of depletions, he determined depletions of Stateline flows that would have affected unused Stateline flows during each month. RT Vol. 86 at 82. His analysis required streamflow records for the Garden City streamflow gage, and since no daily streamflow records were published after 1969, he had no opinion on usable flows for the 1970-85 period. RT Vol. 117 at 101-02, 106. Obviously, this is a severe limitation upon the usefulness of the Colorado evidence.

Helton's approach covered the years from 1950 through 1969, and actually applied to only 169,974 acre-feet of depletions out of the total depletions of 582,694 acre-feet calculated by Colorado. RT Vol. 117 at 103. That is, his analysis did not cover 412,700 acre-feet of depletions, as determined by Colorado, which were caused by pumping after 1969. *Id.* Moreover, Helton concluded that depletions of Stateline flows during the winter were not depletions of usable flow. RT Vol. 117 at 103-04. In essence, he did not consider any winter flows to be usable, and on that basis removed still another 85,536 acre-feet from his calculations. *Id.* at 103-05.

I find that it was incorrect to regard all winter flows as unusable. There is no evidence that the compact negotiators intended such a result. Indeed, Patterson, one of the Colorado commissioners, in the plan he proposed earlier in the ongoing river negotiations, defined usable flow to include winter flows. Jt. Exh. 8 at 23-24. The record shows actual wintertime diversions in Kansas, and these diversions were plotted by the Kansas experts in reaching their wintertime coefficients. Kan. Exh. 684. Winter flows also contribute to usable groundwater recharge.

Helton's methodology included the computation of gains, that is, increases in the flow of the river within Kansas. Colo. Exh. 238*, columns 8, 13, 14. The evidence is not altogether clear on the sources of such gains. Apparently they would include groundwater outflow, return flows, and surface runoff within Kansas. RT Vol. 86 at 48, 50, 63. Helton testified that such gains did not include return flows from deep wells pumping from the Ogallala Aquifer, although that issue was not explored in detail. RT Vol. 86 at 51. Of course, there were also shallow wells in Kansas which pumped from the river alluvium, and presumably some groundwater from these wells would reach the river.

The importance of Helton's calculations of river gains in Kansas is that he allocated all surface diversions first to such gains. RT Vol. 117 at 87. That is, his calculations assume, to the extent of any gains, that Kansas farmers diverted local sources of water rather than taking an equivalent amount of Stateline flows. Whether as a result of his gains analysis or not, Helton concluded that large amounts of Stateline flows were not used, at least in the early postcompact years. Colo. Exh. 238*, column 23. Presumably, in his view, these were flows available for use in Colorado. Asked about his reasons for integrating the concept of gains into his approach, Helton testified, "Well, I think Kansas should be required to use water that is available in Kansas prior to the time that it either makes demands out of conservation storage in John Martin Reservoir or claims a credit for a diversion [by Colorado] of state line flow." RT Vol. 117 at 88.

I find nothing in the record of compact negotiations, or in the compact itself, to support this view. The essence of the compact, apart from the provisions relating to John Martin Reservoir, was to protect the status quo with respect to the division of Arkansas River water between the states. There was no intent that Kansas should be required to make use of other Kansas water supplies before being allowed to complain of uses in Colorado that would materially deplete Kansas' usable share of Stateline supplies.

Helton also included transit losses, that is, seepage going to groundwater recharge, as part of the Stateline flows not diverted. RT Vol. 86 at 52-53, 62. I also find this to be incorrect. The definition of usable flows should include water for groundwater recharge. Kansas made this point in the last meeting of the compact negotiators, without objection from Colorado. Commissioner Knapp stated that uses in Kansas included "not only the actual ditch diversions which are available for measurement, but the water which has gone into ground storage through the years to recharge the pumping area." Jt. Exh. 4 at 17-34. He estimated the amount of water used for groundwater recharge to be about 25,000 acre-feet annually. *Id.*

Helton did not agree with the methodology used by the Kansas experts in determining usable flows, although he acknowledged that Larson's mathematical calculations were correct. RT Vol. 115 at 15, 27; RT Vol. 134 at 29. Helton testified that if the Durbin methodology were to be used, then different coefficients would be more appropriate. RT Vol. 115 at 19, 26; Colo. Exh. 983. His coefficients, which were generally lower than Larson's, were derived from an analysis of Kansas diversions during 1950-69. RT Vol. 115 at 16. These coefficients included the concept of allocating certain diversions to river gains within Kansas. *Id.* Helton's coefficient for groundwater recharge was 6.6 percent, as opposed to 9.9 percent used by Larson.

For his calculations, Larson used the precompact period of 1925-48, excluding the flood year of 1942. Helton's calculations, on the other hand, were based upon the early postcompact period of 1950-69. RT Vol. 115 at 18. Helton testified that this later period was more appropriate because it represented operations under the compact, and a period before wells in Kansas had begun to deplete river flows in large amounts. RT Vol. 115 at 18; RT Vol. 117 at 92-93. He objected to the period used by Larson because it did not represent fully "the operation of John Martin Reservoir and the Arkansas River Compact." RT Vol. 115 at 18. However, the Larson approach more closely matches the amount of flow used for groundwater recharge under precompact conditions. I have concluded that the compact was intended, in part, to reflect generally the division of waters between the states and the uses that had been occurring. Moreover, the period of time selected by Larson does not reflect any increase in recharge that may have been brought about by well development in Kansas.

D. The Spronk Approach.

As part of Kansas' replacement case, Spronk Water Engineers developed a new method to quantify depletions of usable Stateline flows. This procedure depended, in part, upon the reconstruction of daily flow measurements at the Garden City gage. The USGS gage at Garden City was maintained only as a peak flow gage from 1970 to 1985. However, it was learned in the spring of 1991, well after the trial had begun, that although daily streamflow records had not been published, continuous recorder charts were in place during the 1970-85 period. These charts reflected water levels at the gage, that is, "stage heights," from which river flows could then be computed.

Colorado objected strongly to the accuracy of the reconstructed flow records, and this became a subject of considerable testimony. To translate the readings from the water level gage into flow measurements of cubic feet per second, a rating curve is used. Here, the Arkansas River channel is sandy and about 100 feet wide. If the channel changes significantly, a new rating curve must be developed, and in any event, the curve must be checked from time to time against actual flow measurements. In addition to the water level data from the continuous recorder, the USGS made 26 actual measurements of flow during the 1970-86 period, together with some 70 observations of "no flow" and 55 observations of flow but without measurements being made. RT Vol. 108 at 52-53. The argument turned on whether sufficient measurements were taken, and whether the seven different rating curves developed and used during this period were adequate to reconstruct daily flows as used in the Spronk analysis.

Spronk's object was to determine for each day whether all of the Stateline flow was being used. If not, then additional flow at the Stateline on that day was considered to be unusable. As part of that analysis, he assumed that if the outflow at the Garden City gage were less than 5 cfs, then Kansas was fully using the Stateline flow.[128] Spronk's analysis, therefore, did not require refined accuracy. Moreover, Colorado's expert witness acknowledged that the data relied upon by Spronk might be adequate to identify high flows, moderate flows, low flows and no flows. RT Vol. 109 at 19. I believe that the reconstructed gage measurements were probably sufficient for the purpose for which they were used. However, there are more serious concerns with the Spronk approach.

In determining whether Stateline flows were being fully used in Kansas, Spronk applied a number of other factors besides the flow, or lack of it, at the Garden City gage. RT Vol. 89 at 40-43. Overall, the object was to determine the percentage of days in each month when flows were being fully used in Kansas. Those percentages

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[128] Between 1970 and 1973, Spronk used 20 cfs in order to recognize discharges of nonriver water from the Garden City power plant that were introduced into the river just upstream from the Garden City gage.

were then applied to the monthly outputs of changed Stateline flow calculated by the revised H-I model. RT Vol. 89 at 60; RT Vol. 100 at 12-14. For example, in May of 1955, Spronk determined that more flow could have been used in sixteen days of the month, or a ratio of 16/31. That is a percentage of 51.6, which Spronk applied to the depletions calculated for May, 1955, namely 1,043 acre-feet. The result became 538 acre-feet of depletions of usable flow for that month. RT Vol. 89 at 59-61; Kan. Exh. 565***.

Kansas argues that applying long-term averages, as Durbin did, underestimates the depletions of usable flow during the late 1970s and early 1980s. That was a period of drought, and according to Kansas most of the low flows were usable. The Spronk analysis was said to correct this inequity.[129] Kansas states that the Spronk methodology gives substantially the same results as the Durbin analysis, except from approximately 1975 to 1982 when the Spronk analysis more properly represents actual hydrologic conditions. Kan. Opening Br. at 107; RT Vol. 142 at 15-16. However, as Colorado points out, virtually the entire H-I model is based on average data. RT Vol. 142 at 46. Durbin testified to the appropriateness of using averages to represent hydrologic data. RT Vol. 51 at 78. Overall, there is no question about the fact that the

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[129] As the United States notes, the fact that virtually all flows during a dry period may be usable does not "carry this argument." RT Vol. 142 at 48. The more fundamental question is what the Stateline flows and depletions were before usability criteria were applied.

Spronk approach produces the greatest amount of depletions of usable flow. For example, using Spronk's calculations of usable flow, the revised H-I model yields total depletions from both pumping and the WWSP of 489,000 acre-feet for 1950-85. Using the Durbin analysis, with the Larson coefficients, this total drops to 365,000 acre-feet. Colo. Exh. 975, Comparison 1.

Colorado acknowledges that in theory, at least, there is some validity to the daily approach used by Spronk. Colo. Closing Well Br. at 237. However, the Colorado experts testified that the Spronk usable flow method was not appropriate for use with the revised H-I model. The Spronk analysis assumes that the H-I model can accurately predict changes of Stateline flow on a monthly basis. RT Vol. 110 at 126-27; RT Vol. 111 at 32, 38-39, 128-29; RT Vol. 115 at 23-24. I believe the objection is sound.

There was a great deal of testimony by both Colorado and United States experts on this issue, and they generally agreed that the H-I model results were not reliable on a monthly basis. See, e.g., U.S. Exh. 26*, 29; RT Vol. 118 at 92 *et seq.*; RT Vol. 114 at 107-111; RT Vol. 133 at 21.[130]

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130 Although the H-I model was improved by Kansas' replacement experts, the fundamental structure of the model was not changed. Durbin's testimony shows that the model was originally designed to predict changes in Stateline flows. In his opinion, the model was a "good predictor" when "looking at long periods of time." RT Vol. 51 at 72. Using "a long-term average," he testified that the model predicted actual Stateline flows with a "fair degree of accuracy." *Id.* at 84. If multi-year periods were averaged, Durbin said "there would begin to be more and more correspondence between the model and what was actually observed." RT Vol. 44 at 86.

Helton pointed out that the mean absolute deviation[131] at the Stateline, excluding the high flows of 1965, was about 4,200 acre-feet per month compared to an average monthly flow of 10,500 acre-feet. On a monthly basis, he testified that the revised H-I model "did not predict closer than 40 percent." RT Vol. 114 at 111. For the 1976-85 period, the maximum monthly overprediction was 21,018 acre-feet, and the largest underprediction was 19,755 acre-feet. U.S. Exh. 29. Using a standard deviation of error analysis, one of the United States experts testified that 32% of the time the monthly error was greater than 6,000 acre-feet. RT Vol. 118 at 98.

Colorado's experts also criticized the Spronk usable flow analysis because it did not factor out increased losses in the Arkansas River in Kansas due to increased well development in Kansas in the 1970s. RT Vol. 111 at 129, 132-36; RT Vol. 112 at 8-41, 56. To the extent that well development in Kansas may have increased the amount of streamflow going to groundwater recharge, the point is valid. Article IV-D of the compact covers future developments in Kansas, as well as in Colorado. Larson testified that during the precompact years approximately 10 percent of the Stateline flows went to groundwater recharge. If surface flows available for diversion were reduced

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[131] This concept is intended to give a true indication of the difference between observed and predicted values. It eliminates a close correlation based only on simple averages where equal amounts of underpredictions and overpredictions offset one another. Under the "mean absolute deviation" concept, underpredictions (minus values) are treated like overpredictions (positive values), and they are all totaled and averaged. RT Vol. 114 at 108; RT Vol. 118 at 96.

because postcompact wells in Kansas caused streambed percolation to increase, Colorado should not be held responsible.

E. Conclusions.

I conclude that the Durbin approach, using Larson's coefficients, is the best of the several methods presented for determining usable flow. Moreover, I believe this is a reasonable way in which to determine depletions of usable flow.

SECTION XXII

WINTER WATER STORAGE PROGRAM

Most of the final period of the trial, in which the United States played a major role, was devoted to the Winter Water Storage Program ("WWSP"). Kansas' pleadings on this issue focused on its claim that a resolution adopted by the Arkansas River Compact Administration on July 24, 1951 required that any reregulation of the native waters of the Arkansas River be approved by the compact administration. Complaint at 4, ¶ 12; First Amended Complaint at 3-4, ¶ 12. Before trial, however, Colorado filed a motion for partial summary judgment requesting a determination that the compact administration's approval of the WWSP was not legally required. I recommended that Colorado's motion be granted, reserving for trial, however, the issue of whether Stateline flows had actually been materially depleted by the WWSP in violation of the compact. See Part II of this Report. The trial proceeded, therefore, on that reserved factual issue.

A. History of the Winter Water Storage Program.

1. Pueblo Reservoir.

Pueblo Reservoir first appeared as a potential feature of the Fryingpan-Arkansas Project in a 1948 interim report issued by the United States Bureau of Reclamation. Among other project purposes, the report proposed the storage and reregulation in Pueblo Reservoir of the native flows of the Arkansas River, subject to agreements among existing water users. RT Vol. 11 at 126, 128-136; Colo. Exh. 643 at 12. Congress authorized the Fryingpan-Arkansas

Project in 1962. Jt. Exh. 168. Besides the importation of water from the Colorado River watershed west of the Rockies, project purposes included the reregulation of "winter flows of the Arkansas River that are presently diverted for direct-flow use but which, by agreement, could be converted to more beneficial summer use through storage in the Pueblo Reservoir." Jt. Exh. 166 at 32.

In 1964, the Bureau of Reclamation advised the Southeastern Colorado Water Conservancy District[132] that it should begin to develop a program for the storage of winter native flows of the Arkansas River in Pueblo Reservoir. Colo. Exh. 532 at Tab-6 at 6-7. The first winter water storage plan was finalized in 1975 on a three-month trial basis by agreement among the Southeastern Conservancy District and Colorado water users in the Arkansas Valley. RT Vol. 85 at 36, 40-41, 51.

Pueblo Reservoir is owned and operated by the United States, through the Bureau of Reclamation, although other federal and state agencies, including the

[132] The Southeastern Colorado Water Conservancy District was formed in 1958 under Colorado law, among other reasons, to create an organization with powers acceptable to the Secretary of the Interior to enter into a repayment contract with the United States for the Fryingpan-Arkansas Project. Jt. Exh. 104 at 5; RT Vol. 85 at 13, 15-16. The Southeastern Conservancy District signed a repayment contract in 1965 which provided for winter storage in project reservoirs, and included penalties in the form of increased payments for project water if a winter water storage program were not implemented. Colo. Exh. 532, T-3 at 4, ¶¶ 1(e), 6(c), 11(a).

Corps of Engineers, assist with the operation of the reservoir. The WWSP is administered by the Colorado state engineer, based on operating criteria agreed upon by the participating entities. The United States acknowledges that if Kansas is correct that the winter storage program has caused a material decline in Stateline flows, then "the Program should be adjusted, notwithstanding its benefits to Colorado." U.S. WWSP Br. at 2. Federal legislation authorizing the project provides that Colorado's obligations under the Arkansas River Compact shall not be "altered by any operations of the Fryingpan-Arkansas project." Colo. Exh. 545; Jt. Exh. 168.

2. The WWSP.

Winter flows of the Arkansas River have long been used by Arkansas Valley farmers to compensate for the shortage of irrigation water during the summer. A number of canal companies in Colorado have private reservoirs and appropriate storage rights to store such off-season flows for later use during the summer irrigation season. In addition, farmers in Colorado and western Kansas have diverted water for winter irrigation, that is, diversion of water onto bare fields during the nongrowing season. This practice allowed farmers to take advantage of what otherwise would have been unusable water by increasing the soil moisture for later use by crops during the growing season. However, winter irrigation is affected by weather, and is subject to relatively high rates of evaporation from the wet soil. The Colorado Supreme Court has stated:

> "Winter irrigation is a difficult, less efficient method of irrigation. If possible, a much preferable operation is to store the direct flow winter water and use it later in the year." *Purgatoire River Water Conservancy Dist. v. Kuiper*, 593 P.2d 333, 335 (Colo. 1979).

Winter irrigation below John Martin Reservoir in Colorado generally ended with construction of that reservoir and adoption of the Arkansas River Compact. Under the compact, all winter flows entering the reservoir are stored, subject to the release of river flow not to exceed 100 cfs upon demand by Colorado. Article V-A.

As the Winter Water Storage Program has currently evolved, it operates during a four-month period beginning November 15 and ending March 15 of the following year. Jt. Exh. 22 at 17. The program commenced in 1976, but did not operate during 1977-78. Present participants in the WWSP include all of the major ditch and reservoir companies that have historically diverted from the Arkansas River between Pueblo Reservoir and John Martin Reservoir, except the Otero Ditch Company and the Rocky Ford Canal Company.[133] Jt. Exh. 22 at 22. These participating companies store water during the winter months in Pueblo Reservoir, in John Martin Reservoir,

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133 The participants are the Amity Mutual Irrigation Company, The Bessemer Irrigating Ditch Company, the Catlin Canal Company, The Colorado Canal Company, The Fort Lyon Canal Company, The High Line Canal Company, The Holbrook Mutual Irrigating Company, The Lake Henry Reservoir Company, The Lake Meredith Reservoir Company, the Las Animas Consolidated Canal Company, The Oxford Farmers Ditch Company, the Riverside Dairy Ditch, and the West Pueblo Ditch.

and in various off-channel reservoirs, and it is then released for use later in the year. RT Vol. 82 at 152. Arkansas River flows during the winter months are relatively small, and almost the entire winter flow of the river above John Martin Reservoir is now diverted and stored in reservoirs. RT Vol. 83 at 76-78. Winter irrigation has essentially been supplanted. Total storage under the program has varied from 94,793 acre-feet in 1978-79 to 216,886 acre-feet in 1986-87. Colo. Exh. 210. There are no limits on the amounts of winter water that can be stored except for the capacities of the reservoirs.

The WWSP, which went through a series of annual changes, was finally approved by a decree of the Colorado Water Court in 1987. RT Vol. 85 at 40, 56-57; Jt. Exh. 22. The decree basically confirms the operating plan that had been in effect since 1983. RT Vol. 86 at 9. Under the plan, the first 100,000 acre-feet of water stored during the winter is allocated among the WWSP participants according to percentages, with 71.2% of the water being allocated to those holding off-channel storage rights, and 28.8% to those participants owning direct-flow rights only. Jt. Exh. 22 at 18-19. The next 2,750 acre-feet of winter stored water above 100,000 acre-feet is allocated to the Amity Mutual Irrigation Company, which may store it in the Great Plains Reservoirs or John Martin Reservoir. The next 356 acre-feet is allocated to the Holbrook Mutual Irrigating Company. Amounts of winter-stored water above 103,106 acre-feet are allocated among the WWSP participants according to a second set of percentages. Jt. Exh. 22 at 19-20. In part, the allocation formulas reflect long-term average diversions by the participants, but in part they are the result of negotiations among the various companies. RT Vol. 85 at 39-40, 93-96, 121-22.

3. Development and Implementation of the WWSP.

Colorado urges that Kansas, with full knowledge, acquiesced in the development and implementation of the WWSP, and therefore should not now be heard to complain. Colo. Closing WWSP Br. at 64-65. Acquiescence was not specifically raised by Colorado as a defense in its answer, although other equitable defenses were pled. In a case of this kind, however, the issue should not be foreclosed by an overly narrow view of the pleadings.

There is no doubt that Kansas was kept well informed about the development of the WWSP. In 1969, the Southeastern Conservancy District formed a Winter Storage Committee which included representatives of all entities eligible to participate. Chairman of the Board of Trustees of this committee was Charles L. ("Tommy") Thomson. RT Vol. 85 at 30-31. Thomson began to inform Kansas of developments at least as early as 1970 when he reported to the Arkansas River Compact Administration at its annual meeting. RT Vol. 85 at 36-37. He testified that thereafter "It more or less became an annual exercise that I would go down and tell them how we were getting along." *Id.* at 37.

In December of 1975 Thomson reported to a meeting of the compact administration that the program was being inaugurated on a three-month "experimental basis." Colo. Exh. 532, Tab 13. The compact administration was complimentary, and established a special engineering committee "to report to the Administration at each annual meeting the opinion of that committee of the relationship between Fryingpan-Arkansas Project and the Arkansas River Compact Administration." Colo. Exh. 532, Tab 13. Guy E. Gibson, one of the Kansas members of the compact administration and the Kansas Chief Engineer, Division of Water Resources, was appointed to that committee. RT Vol. 85 at 60. Gibson was also placed on the mailing list for the minutes and other documents from the Southeastern Conservancy District's Winter Storage Committee. Colo. Exh. 532, Tab 11, Tab 25, Tab 26. In short, there is ample evidence that the Kansas representatives "were fully aware of the program and how it had been put together and how it was to be operated, but it was understood by everybody that it was an experimental program and the results were to be evaluated." RT Vol. 85 at 67 (Thomson).

Before approval by the Colorado Water Court in 1987, the WWSP operated on a voluntary basis that required unanimous agreement. Operating plans for the WWSP changed from year to year from 1975 to 1983 when the current formula for allocating water among the participants was adopted. Colo. Closing WWSP Br. at 63. While the program was still being implemented on an interim or trial basis, Kansas expressed concern at the December, 1980 meeting of the compact administration over potential reduction of inflow into John Martin Reservoir resulting from the program. Colo. Exhs. 538, 545. Kansas suggested that a study be made, which was in fact undertaken by the USGS and completed in February, 1981.

The USGS performed a double-mass curve analysis of streamflow records for 1967-79. The survey found that the data did not indicate that inflow to John Martin Reservoir had been reduced as a result of the storage of winter water in Pueblo Reservoir. Colo. Exh. 538. These results coincided with a computer model analysis made by the USGS in 1975. Using a study period from only 1972 to 1974, and certain assumptions about the nature of the program, the computer analysis predicted an average annual increase of 7,300 acre-feet across the Stateline. Jt. Exh. 88 at 4.24-26. Also in 1981 the Kansas Division of Water Resources reviewed the data and concluded that comparative flows did not show a "reduced flow at the Las Animas gage . . . since operation of Pueblo Reservoir began." Colo. Exh. 539.

Thus, the early and preliminary reviews of winter water storage did not indicate any adverse impact upon Kansas, and there is nothing in the record to suggest any contrary intent. Under the circumstances, I am not persuaded that Kansas should be deemed to have acquiesced in violations of the Arkansas River Compact resulting from the storage of winter water, if indeed material Stateline depletions should prove to be a consequence of that program.

Colorado also argues that Kansas benefited from the storage of winter water in John Martin Reservoir, especially after the 1980 Operating Plan became effective. Having accepted benefits from the WWSP, Kansas should not be permitted, urges Colorado, to claim injury from the program. Colo. Closing WWSP Br. at pp. 64-66. Storage in John Martin Reservoir was not the major thrust of the WWSP. However, as I concluded in Section XIV, the 1980 Operating Plan provided benefits to both Colorado and Kansas. Consideration was given and received by both states. Kansas did not trade depletions of Stateline flow which are in violation of the Arkansas River Compact in return for benefits under the 1980 Operating Plan.

Kansas also adds that an agreement between the states, without the consent of Congress, cannot alter their respective rights and duties under the compact. *Texas v. New Mexico*, 462 U.S. 554, 564, 567-68 (1983). See also Kan. Exh. 751 (United States Brief in *Oklahoma and Texas v. New Mexico*). However, Colorado responds that the compact has not been unlawfully modified, that adoption of the 1980 plan was well within the powers of the Arkansas River Compact Administration. Be that as it may, the issue of whether the 1980 Operating Plan alters the compact without the required consent of Congress is not before the Court in this case. The fact is that the 1980 plan is in effect with the consent of both states. The issue now raised is whether Kansas' conduct in relation to the plan should invoke equitable defenses. For the reasons given here and in Section XIV, I have concluded that Kansas should not be barred by equitable considerations from pursuing its claim against the WWSP.

B. Results of the Computer Models.

Both Kansas and Colorado modeled the impact of the Winter Water Storage Program. The United States, on the other hand, reviewed the revised H-I model in depth and developed the capability to operate it, but did not construct a model of its own.

The depletions to usable flow predicted by the original version of the H-I model are summarized in Kansas Exhibit 112* (12-6-90). For the WWSP, this exhibit shows depletions of 255,000 acre-feet. Comparison H; RT Vol. 88 at 131. In this comparison, it should be noted that Durbin left the switch "on" for the 1980 Operating Plan. The replacement experts, however, took a contrary view and turned that switch "off" in order to isolate the WWSP impacts. RT Vol. 88 at 133-35. The depletion figure of 255,000 acre-feet is the result, in part at least, of the serious coding error found by Colorado in the H-I model. In evaluating the overall persuasiveness of the Kansas case, this original evidence cannot be forgotten or ignored.

Kansas' replacement experts corrected the coding error, made other changes to the model, and then lodged Kansas Exhibit 111**. This exhibit showed the WWSP impacts on usable flow at 44,000 acre-feet. RT Vol. 88 at 132-33. But even that amount turned out to be incorrect. As part of his direct examination, Spronk testified that the input file used in the revised model for the amount of decreed storage available in the Great Plains Reservoirs should have been 223,221 acre-feet instead of 166,892 acre-feet. RT Vol. 88 at 141-42. As a result of this additional change, the depletion figure of 44,000 acre-feet calculated by the revised H-I model dropped to 40,000. Kansas then prepared Exhibit 111*** to reflect the corrected figures. Colorado was plainly frustrated over this latest revision, and complained of the prejudice resulting from abruptly finding out that "everything we did has to be redone." RT Vol. 88 at 143. My disappointment was also evident, although it appeared that Kansas was attempting to get it right. *Id.*

Kansas' final WWSP evidence, presented through its replacement experts, showed total depletions of 53,000 acre-feet, and 40,000 acre-feet of depletions to usable flow. Kan. Exh. 111***.[134] These calculations, however, did not account for return flows from transmountain imports. If these are considered, Spronk testified that depletions to usable flow amount to only 5,000 acre-feet for the entire period of program operation (1976-85). Kan. Exh. 651. Kansas, however, objects to such an offset, arguing that Colorado offset those return flows against pumping, and that no party has suggested that the benefits of imported water be used to reduce WWSP depletions alone. Kan. Comments on Draft Report at 9, 15, 45. In any event, the parties appear to agree that care must be taken not to "double-count" the offset effect of transmountain return flows.

Colorado also presented evidence regarding the WWSP. Helton testified that there was "no discernible impact" on Stateline flows from the WWSP. RT Vol. 115 at 59-60; RT Vol. 86 at 88. Besides the results of Colorado's computer study, he relied on his own work with irrigators and his "observation of what the operations actually were during the winter storage program."[135] RT Vol. 115 at 60.

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[134] This usable flow figure is derived from the Spronk analysis. If Durbin's methodology with Larson's coefficients are used, the result is 27,000 acre-feet. Colo. Exh. 975, Comparison 3.

[135] Helton was one of Colorado's two representatives on the special engineering committee formed by the compact

Colorado used its water budget to analyze the effects of the WWSP under a study called a "What-if 1" comparison. Colo. Exh. 134* at 8.1. However, unlike Kansas, Colorado did not analyze the WWSP for the years when it was actually operating. Instead, Colorado superimposed the program on the historic period of 1950-75 and 1978, that is, during the years when the program was *not* in place. Colorado did not think it was possible to predict reliably what the winter diversions would have been after 1976 under an assumption that the program was not in operation. Even so, Kansas says that the Colorado analysis is "simply for the wrong period."[136] Kan. Opening Br. at 97.

I cannot say that it was legally wrong for Colorado to simulate the operation of the WWSP over an historic period.[137] However, I believe it is more appropriate to

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administration in 1975 to review and analyze the program, and to report back to the administration. Colo. Exh. 532, Tab 13.

[136] Kansas was also critical of a number of incorrect assumptions in Colorado's analysis which had the effect of overstating evaporation or consumptive use under historic winter irrigation practices, and thus understating the impact of the WWSP. See, e.g., failure to cut off winter soil evaporation at temperatures below freezing, RT Vol. 103 at 59; assuming that winter irrigation water was applied to all of the lands of the WWSP participants, RT Vol. 114 at 149; and underestimating tailwater returns during the winter months, e.g., winter return flows from the Fort Lyon Canal were calculated to be zero for all years from 1950 through 1984. Kan. Exh. 735, RT Vol. 134 at 110-11. Moreover, the Colorado analysis assumes there were no depletions above the Las Animas gage. RT Vol. 116 at 131-32.

[137] This was in fact the technique used by the Bureau of Reclamation in evaluating the potential impact of the Trinidad Project. Studies were done in 1961-64 using the period of

evaluate the actual operations of the WWSP. There is a continuing obligation to implement the program in accord with the Arkansas River Compact, and in the future it will become increasingly important to determine compliance on a current basis. To conclude that the program would not have caused Stateline depletions if it had been operated under 1950-75 conditions does not necessarily establish that future operations, under perhaps quite different hydrologic and cultural conditions, will not cause depletions.

However, the Colorado water budget analysis does show some limited depletions, in excess of 9,000 acre-feet for the 27 year period studied, or about 354 acre-feet per year on average. Calculated from Colo. Exh. 134* at 8.1, Col. 16; RT Vol. 134 at 113. Apparently the 9,000 acre-feet figure would represent depletions of total flow as opposed to usable flow, although I found no specific evidence on this point.[138]

C. Position of the United States.

Initially, the United States questions whether Kansas' expert testimony based upon the revised H-I model satisfies threshold standards of reliability, citing the Supreme Court's recent decision in *Daubert, et al. v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. ___, 125 L.Ed.2d 469 (1993).

1925-57 to simulate operation of the proposed reservoir. Jt. Exh. 24a, 24b. Of course, these were preproject studies. There was no opportunity in 1961-64 to analyze actual operations.

[138] Kansas understood that this figure related to total, not to usable flows. RT Vol. 142 at 56.

I note that the decision is limited to the "scientific" portion of Rule 702 although the rule also applies to "technical, or other specialized knowledge." Moreover, the discussion is seemingly aimed at jury cases. Nonetheless, if the decision, including the "general observations" of the Court, does apply to all of the expert testimony in this case, I believe that *admissibility* requirements have been met. The real issue here, however, is whether Kansas' expert testimony, based as it is largely upon the results of the revised H-I model, is sufficiently persuasive to carry the burden of proof with respect to the WWSP. For reasons later discussed, I do not believe that it is.

The United States intervened in the case well after preparations for trial by the two states had begun. At the outset, the United States did not have access to the new data being developed by experts for the states, e.g., amounts of pumping, diversions, irrigated acreage, storage data, and consumptive use by phreatophytes. RT Vol. 119 at 115. The United States' experts attempted to make a water balance of the surface and groundwater system of the Arkansas River in Colorado. However, because of the lack of data they could not determine from that analysis whether the WWSP had an impact on Stateline flows, "either positive or negative." RT Vol. 119 at 113. Nor did they believe, with the current data then available, that they could develop their own model. *Id.* at 120. Instead, the United States' experts concentrated their attention on

Kansas' revised H-I model.[139] No similar effort was made to analyze the Colorado water budget.

The two principal experts for the United States both testified that they did not know whether the WWSP had any impact on Stateline flows, "plus or minus." RT Vol. 120 at 78. Moreover, given the relatively small magnitude of the claimed impacts of the WWSP, and the present state of knowledge, Mr. Finlayson did not believe that a model could be constructed "to determine that impact with a reasonable degree of accuracy." RT Vol. 120 at 74. The basic problem, he testified, lies in attempting to take a single change in the use of a relatively small amount of water, and to route that change from Pueblo to the Stateline. RT Vol. 120 at 23.

However, the Deputy Assistant Commissioner, Resources Management, of the Bureau of Reclamation expressed a different view.[140] Concerning the WWSP, he testified that the Bureau recognizes an obligation not to cause a material depletion in Stateline flows, and that in his opinion the Bureau has been meeting that obligation. RT Vol. 122 at 52. On questioning from me, however, it

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[139] These expert witnesses were Donald J. Finlayson and Charles W. Binder. Mr. Finlayson served with California Department of Water Resources for some 30 years, retiring as Chief of its Planning Branch. His experience and qualifications are set forth in U.S. Exhibit 47*. Mr. Binder holds a 1981 master's degree in civil engineering from Colorado State University. He has worked for Simons, Li & Associates and Spronk Water Engineers. Since 1989 he has been employed by David Keith Todd in Berkeley, California. His qualifications appear in U.S. Exhibit 46.

[140] Raymond H. Willms, located in Denver, Colo.

became apparent that he was essentially relying on assurances from Colorado. "They have indicated to us that they operate it [WWSP] without impairing or causing a material depletion of the compact." RT Vol. 122 at 53. While the Bureau had not seen any indication of impairment, Willms acknowledged that the Bureau itself had not made any independent studies and was going ahead with its part of the program on the assumption that it was being properly administered by Colorado. RT Vol. 122 at 53. It should be noted that the federal facilities are only part of the WWSP; that Willms testified that there cannot be "two masters" here; and that the Bureau generally leaves the administration of water rights to the states. RT Vol. 122 at 19-20.

As part of the post-trial briefing process, I inquired of counsel concerning the United States' position on WWSP compliance with the compact – that is, whether the program is indeed in compliance or the United States does not know. Counsel for the United States replied, "Under our interpretation, the WWSP is in compliance with the Compact, which specifically provides for new beneficial development such as the WWSP." Aug. 24, 1993 letter at 3. Noting that such new development is obligated not to cause material depletions, counsel nonetheless went on to state that the compact "does not require affirmative proof of 'no depletion' before development can go forward." *Id.* Rather, the United States concluded, "beneficial developments with no known or obvious adverse impacts seem to be permitted under the Compact unless shown to have caused disallowed depletions." *Id.* (It should be recalled that the United States would also require Kansas to establish any compact violation by "clear and convincing" evidence.)

I am not persuaded that the United States should have so little responsibility. Pueblo Reservoir is a major storage facility, and to alter the regime of the Arkansas River by storing winter flows is not a trivial change. The compact is a law of the United States, binding on the Bureau of Reclamation as well as on the States of Kansas and Colorado. *Texas v. New Mexico*, 462 U.S. 554, 564, 77 L.Ed.2d 1, 103 S.Ct. 2558 (1983). In a development of this kind, the United States should not operate the project or participate in its operation, without a good faith belief, based on whatever data or studies may be needed, that the United States is acting in full compliance with the law. This is not to suggest that United States' officials have not been acting in good faith. But their beliefs appear to rest primarily on assurances from Colorado, without independent review or confirmation.

D. United States Critique of the Results of the Revised H-I Model [WWSP].

The central thrust of the United States' case is that the revised H-I model is not sufficiently reliable or refined to prove Stateline depletions from the WWSP. According to Kansas' own evidence total depletions to usable flow over a nine-year period of operations (1976-85, except for 1978) amount to 40,000 acre-feet. If the Court accepts my recommendation on the methodology to be used for the calculation of usable flows, then the 40,000 acre-feet amount is reduced to 27,200 acre-feet.

Colo. Exh. 975. If accretions are considered, the depletions are eliminated entirely. *Id*. The essence of the United States' position is that the ranges of error or uncertainty in the H-I model results, whether considered on an annual or monthly basis, are far greater than the depletions sought to be calculated. A shortage derived from the model results may well reflect only model error, not the real impact of the WWSP. As one Colorado expert put it, "the error is simply a lot bigger than the effect we are trying to find." RT Vol. 133 at 24. The United States is not unsympathetic to the fact that this is "an extremely complex modeling problem," but such difficulty only stiffens the need for reliability. U.S. WWSP Br. at 6.

The United States introduced a series of exhibits comparing the Stateline flows predicted by the revised H-I model with those actually observed. This was done on both an annual and monthly basis, and certain exhibits excluded the extraordinarily high flood flows of several "outlier" months; these last exhibits are the ones I have used for comparative purposes. Observed Stateline flows are tabulated in U.S. Exhibit 24*, predicted flows in U.S. Exhibit 25*, and the differences in U.S. Exhibit 26*. In 6 of the 10 years in which the WWSP was simulated, the error between predicted and observed flows exceeded 30 percent. The largest overprediction was 31,416 acre-feet (for 1979), while the greatest underprediction was 19,526 acre-feet (for 1978). In the three years in which the error was less than 10 percent, the magnitude of the difference in flows still averaged 12,251 acre-feet.

The United States contrasts these figures with average annual net depletions from the WWSP of only 1538 acre-feet. U.S. WWSP Br. at 28. However, this is not the amount of Kansas' claim since this depletion estimate is the result of two very large months of accretions.[141] When these accretions for these months are removed, Kansas claimed depletions from the WWSP average 4,739 acre-feet per year. U.S. Exh. 18; RT Vol. 118 at 69-70.

The United States' experts also presented an "error analysis" of the predicted versus observed Stateline flows on a monthly basis. U.S. Exh. 29. For the period of time before the WWSP was in operation (1950-75), monthly Stateline flows averaged over 10,500 acre-feet, excluding the outlier months. U.S. Exh. 24*; U.S. WWSP Br. at 26. During this time, the absolute average error in the monthly model predictions was 3,642 acre-feet.[142] U.S. Exh. 29. For the period of 1976-85 when the WWSP was in place, this average monthly error was 3,793 acre-feet, and for 1980-85 it increased to 4,566 acre-feet. *Id.* Monthly predicted and observed flows are shown on U.S. Exhibit 36, together with the monthly impact of the WWSP as calculated by the revised H-I model. For the 1976-85 period, predicted flows exceeded actual flows by an average (not absolute average) of 2,084 acre-feet per month. RT Vol. 118 at 85. This can be contrasted with average predicted depletions of 475 acre-feet per month, or 128 acre-feet if accretions are considered. *Id.*

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[141] 17,416 acre-feet in May, 1985 and 13,889 acre-feet in June, 1985. U.S. Exh. 18; RT Vol. 118 at 67-71.

[142] As used by the United States, the concept of absolute average error sums up the actual amount of error that occurred for each month, rather than a long-term average which allows positive and negative values to cancel out. Helton used the term "mean monthly absolute deviation" to describe the same concept.

Mr. Charles W. Binder, one of the United States experts, acknowledged that during the pre-WWSP period (1951-75) the revised H-I model had "virtually no error" when considering long-term, average annual results.[143] *Id.* at 85-86. However, during the WWSP years, the United States evidence showed that the Kansas model overpredicted Stateline flows by an average of some 13,507 acre-feet a year. U.S. Exh. 26*. Binder testified that this change indicates errors in the model that do not allow it to predict accurately during the period of the WWSP operation. RT Vol. 118 at 72, 85-86, 88.

Kansas argues strongly that it is a "fundamental misconception" to evaluate the accuracy of the revised H-I model by comparing predicted to observed flows. RT Vol. 142 at 25-26, 55. To be sure, the model was calibrated against actual, historic flows. Yet, Stateline depletions are not determined on that basis, but rather by taking the difference between two model runs that reflect different institutional conditions. As Mr. Larson testified, this permits errors in data or assumptions to cancel out since they are common to both runs. RT Vol. 99 at 29-30; see also RT Vol. 101 at 19-20, 22, 25; RT Vol. 118 at 100. The model has always been viewed as a better predictor of *changes* in Stateline flows than as a predictor of actual Stateline flows. RT Vol. 44 at 91-92; RT Vol. 51 at 72. However, in assessing the WWSP impacts, Kansas compared two hypothetical situations without a common base. Kansas did not model the real WWSP, as it has been operating. Under those circumstances I do not find it

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143 The model underpredicted by about 2,500 acre-feet per year. U.S. Exh. 26*.

inappropriate to consider actual flows and conditions in evaluating the model results.

To prove that the WWSP caused a material decline in Stateline flows, Kansas computed the difference between flows from two model runs, each of which has the 1980 Operating Plan simulation removed. These are the WWSP run (HHCH), and the winter irrigation run when the WWSP was not simulated (HCCH). Kansas argues that it was necessary to turn the switch "off" on the 1980 Operating Plan because the plan and the WWSP are so closely tied together; if the model run does not include the WWSP, it is said that operation of the 1980 Operating Plan should not be simulated either. In effect, experts for Kansas made the engineering judgment that the 1980 plan would not continue without the WWSP. As a result, there is no model run that reflects actual historical conditions. RT Vol. 142 at 90. In simulating the WWSP, Kansas does not include winter storage in John Martin Reservoir, although Amity, Las Animas and Fort Lyon actually stored winter water in that reservoir under the WWSP.

Both the United States and Colorado also point out that certain problems present in the WWSP runs will not cancel out because the errors are not parallel. For example, one of the principal factual issues concerns the amount of evaporation occurring from winter irrigation. The United States and Colorado both claim that Kansas has underestimated this figure. To the extent this is true, return flows are increased and Stateline flows become larger. However, if indeed Stateline flows are in error, there would be no comparable overstatement of streamflows in the companion WWSP run because in that run winter water is stored, and not subjected to evaporation from bare fields. The issue of winter soil evaporation is discussed more fully in the following subsection.

The H-I model also overpredicts the amount of water actually put into storage by about 141,500 acre-feet. Colo. Exh. 894. Colorado calls this a "real error" that does not "wash out against anything." RT Vol. 143 at 62-63. In the comparison simulation, that is in the model run without the WWSP being operated, there is no comparable storage figure. Instead, it is assumed that winter flows are applied directly to bare fields for irrigation.

The United States also joins in many of the general criticisms of the revised H-I model made by Colorado.[144]

E. Accretions from the WWSP.

Finally, both the United States and Colorado urge that accretions must be considered when evaluating the impacts of the WWSP. If this is done in conjunction with the usable flow analysis recommended in Section XXI of this Report, the revised H-I model reduces depletions to 2,200 acre-feet for the whole nine year program, or calculates an actual increase in Stateline flows, depending

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[144] Besides winter evaporation issues, the United States complains about the use of the WTADD factor to limit winter diversions; the use of a 10% tailwater factor that is too high; the diversion reduction factor; the artificial reduction of canal capacities; assumptions re Kansas demands affecting releases from the conservation pool; the assumption of linearity of the groundwater model; failure to match monthly diversions; overprediction of off-channel storage during the WWSP simulation; and departures from actual timing and amounts in simulating storage in John Martin Reservoir.

upon how the institutional switches are set for the 1980 Operating Plan. Colo. Exh. 975, Comparisons 3, 7. Kansas objects, noting that of the 37,000 acre-feet of accretions occurring during the 1976-85 period, 31,000 acre-feet occur in two months in 1985, right at the end of the period. Kan. Exh. 565*** at 8. However, the timing of any accretions (as well as depletions) becomes a product of the assumptions and parameters used in the modeling effort. It seems likely that a reservoir storage program could well provide some usable accretions that would mitigate depletions.

The evidence shows that in seven of the nine years during which the WWSP operated, the H-I model put more water into storage in John Martin Reservoir than actually occurred. U.S. Exh. 8; Colo. Exh. 899. As a result of this artificial storage buildup, the model calculated that John Martin Reservoir filled in 1985, finally producing a model spill of 255,000 acre-feet. Colo. Exh. 980. An actual spill did occur in that year, but it amounted to only 87,000 acre-feet. *Id.* The United States and Colorado thus argue that the H-I model held water in storage that in truth moved downstream over the years to add to Stateline flows. However, in terms of model results, when the stored water was spilled during two months in 1985, the flows show up as "accretions." And Kansas disregards such flows as not being usable or timely if they are to be used to reduce depletions that occurred earlier in the WWSP period. There is not sufficient evidence to determine what the impact on Stateline flows would have been if the H-I model had more closely corresponded to actual storage in John Martin Reservoir and to actual releases.

However, there seems to be merit in Colorado's argument, with respect to the WWSP and accretions, that the H-I model has created "false depletions." RT Vol. 142 at 80.

F. Winter Irrigation Evaporation.

Whether the WWSP does result in Stateline depletions depends on a comparison of consumptive use under the program with prior winter irrigation practices. Kansas maintains that storing the winter river flows in reservoirs, and then applying that water to irrigated crops in the summer, uses more water than simply irrigating bare fields in the winter. On first impression, this would seem to be true. Indeed, that was even Schroeder's reaction, that is, that the program "would seem to deplete the state line flow." RT Vol. 111 at 143-45. However, the issue is much more complex than first appears, and a great deal of highly technical evidence was introduced on the subject. The issue turns largely on the amount of evaporation from bare soil that is assumed during the period when winter irrigation was practiced.

When water is applied to bare soil in the winter, the water at or near the soil surface evaporates at a high rate. The United States' expert testified that the evaporation rate from wet soil is at or near the rate of lake evaporation. RT Vol. 136 at 52-53. Water that is not evaporated is stored in the soil profile and held there against gravity until the water-holding capacity is exceeded. The excess then percolates down to the next layer of soil or into deep percolation. *Id.* at 20-34. The water retained in the soil profile is either evaporated at a slower rate, or is available for use by the crop during the next growing season. *Id.* at 47-52; RT Vol. 114 at 147-155. Of course, there is also a certain amount of tailwater runoff that reaches the river from such winter irrigation. The amounts of water that are evaporated, or retained in the soil profile for crop consumption, or percolate into the groundwater, vary with the season, soil, weather, and amount and timing of applied irrigation water.

The physical process of soil evaporation involves two separate phases or "stages." The first phase occurs when the top profile of soil, from four to six inches, is wet, and the rate of evaporation is limited by the evaporative capacity of the air. Colo. Exh. 659. During the second stage, after the top of the soil has dried out, evaporation still continues but at a slower rate. RT Vol. 136 at 74; U.S. Exh. 61 at 48. However, soil evaporation from water applied to bare fields in the winter is not well documented in the literature. Colo. Exh. 659. Much of the available data relate only to soil evaporation during the growing season.

For use in the development of the H-I model, Kansas' experts prepared a memorandum reviewing the available information about winter evaporation. Colo. Exh. 659. As a result, Kansas adopted a modified Blaney-Criddle equation for the determination of winter soil evaporation. Book testified that he knew of four prior studies along the Arkansas River where this methodology had been used to determine winter soil evaporation. RT Vol. 126 at 92-96. The engineering data used in one of these studies involving the Kessee ditch had been submitted to and approved by the engineering committee of the Arkansas

River Compact Administration. *Id.* at 92-93. In its application of the Blaney-Criddle equation in the H-I model, Kansas applied a coefficient of .2 for potential evapotranspiration (PET). From all the data available, Book believed that this was a reasonable figure. RT Vol. 126 at 105.

Colorado, on the other hand, employed a formula known as the Ritchie equation for the determination of winter soil evaporation. This methodology was strongly supported by the United States; indeed, the United States' expert testified that not only was the Ritchie formula by far "the best way of calculating soil evaporation," but that other methods were "not even appropriate."[145] RT Vol. 136 at 96. Colorado's use of the Ritchie equation produces higher amounts of winter soil evaporation than the Kansas analysis. The difference is approximately 15%, or an average of about 12,000 acre-feet annually for the 1950-85 period. RT Vol. 125 at 74-75; RT Vol. 126 at 133, 146-47; Colo. Exh. 862. Of course, higher estimates of evaporation from winter irrigation reduce the historic contributions to the river from such winter diversions, and lessen any depletions under the WWSP.

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[145] Testimony of Dr. Robert D. Burman, Professor Emeritus of Agricultural Engineering at the University of Wyoming. His resume is U.S. Exh. 60. Dr. Burman chaired the American Society of Civil Engineers' Committee on Irrigation Water Requirements for over ten years, and is the co-author of the ASCE publication, "Evapotranspiration and Irrigation Water Requirements."

Colorado argued that the PET used in the revised H-I model acted as a ceiling and did not allow evaporation to increase with larger applications of irrigation water. RT Vol. 138 at 58. Schroeder, therefore, made a change to the revised H-I model. He removed the PET cap so that evaporation was calculated in a manner similar to that in Colorado's water budget. RT Vol. 138 at 64, 67; RT Vol. 139 at 65. The result of this one change essentially cut the depletions calculated by the revised H-I model in half.[146] Colo. Exh. 1012, Comparison 4. However, Kansas objected that such a change was not appropriate, claiming that the H-I model is a "one-layer" model. To remove the PET cap allows access to the entire soil moisture reservoir. RT Vol. 125 at 76. An increase in the PET results in a like amount of actual consumption in the Kansas model. *Id.* This is unlike the Colorado "two-layer" model, which can isolate part of the soil moisture, not allowing it to evaporate. *Id.* Schroeder also acknowledged that he did not recalibrate the revised H-I model after his change. RT Vol. 139 at 64. Thus, while Schroeder's results may not be appropriate or reliable, they do emphasize the importance of accurate winter evaporation data in evaluating the WWSP.

On surrebuttal, the United States called Dr. Burman as an expert witness on the evaporation issue. His principal points were that the PET coefficient used by Kansas was too low, and that Kansas should have employed the Ritchie equation instead of the modified Blaney-Criddle

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[146] Total depletions from the WWSP were reduced from 53,440 acre-feet to 25,532 acre-feet. Similar reductions occurred in depletions of usable flow.

methodology.[147] He pointed out that the Kansas approach cannot be adjusted to reflect the different number of irrigation applications or "wettings." RT Vol. 136 at 98. The H-I model recognizes only average wettings, with the result that it does not properly simulate stage one events and underestimates actual evaporation. RT Vol. 137 at 9-10. The Ritchie equation, on the other hand, addresses both stages of evaporation and the wetting frequency. However, the Ritchie equation requires the use of a two-layer model. RT Vol. 126 at 97-98, 108. While the Ritchie equation may be more refined, and possibly more accurate, it cannot be used in a one-layer model like the revised H-I model. *Id.*

It is not clear, however, that reasonable results can be obtained only through the use of the Ritchie equation. While Dr. Burman is described by counsel for the United States as "one of the most knowledgeable experts in the world in the physical processes that govern the consumption of irrigation water," he knew of no instance, apart from this case, where the Ritchie equation had been used to model the evaporation of winter irrigation water. RT Vol. 137 at 52, 60. He himself had never applied the Ritchie equation to winter soil evaporation. RT Vol. 135 at 98. Apart from work in another current case, he had never developed a computer program to model soil moisture accounting. *Id.* at 90, 96. Indeed, he had never made a study of evaporation from bare soil. RT Vol. 137 at 52-53; RT Vol. 135 at 97. Moreover, he acknowledged that

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[147] Another U.S. expert, however, appears to have used Blaney-Criddle in the early stages of his investigation. RT Vol. 119 at 117.

the Ritchie equation should be applied on a daily timestep, and that the required records of lands on which water was used are not available on a daily basis. RT Vol. 137 at 52-53, 58-59. He had no opinion on what the proper value for PET should be, although in his view the Kansas modeling approach did not lend itself to an appropriate PET value. RT Vol. 137 at 12.

The weight of his testimony was subject to further question by the fact that the form of the Ritchie equation published in his 1990 book was incorrect.[148] RT Vol. 137 at 22-26, 30, 32; Kan. Exh. 699. This might not be a worthy consideration (counsel for the United States says the error was a typographical mistake only) except for the persistent cross-examination that was required to get him to appreciate the error. Moreover, his testimony on the stage one evaporation portion of the equation was far from clear. His own calculations applying the Ritchie formula omitted a reduction called for by the equation. RT Vol. 137 at 14-22, 102-04. He used "straight lake evaporation" as opposed to applying a 10 percent reduction included within the equation. *Id.* at 103.

In the final analysis, modeling winter evaporation depends not only upon the equation used but also on the amounts and frequency of the irrigation applications, and weather conditions at those times. However, that determination need not be made in order to decide the present WWSP claim. I have concluded that the depletions shown

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[148] The equation is 4.11 on page 49 of U.S. Exh. 61. This is commonly known as Manual 70, published by American Society of Civil Engineers, entitled *Evapotranspiration and Irrigation Water Requirements*.

by the Kansas model are well within the model's range of error. One cannot be sure whether impact or error is being shown. Nonetheless, it is evident that winter evaporation is an important factor in evaluating the WWSP, and one would hope that appropriate field studies could eventually be made to provide more reliable evidence on this issue.

G. Conclusions re WWSP.

I conclude that Kansas is not barred by equitable considerations from pursuing a claim under the compact against the operation of the Winter Water Storage Program. However, even if the standard of proof is a preponderance of the evidence, I find that Kansas has not proved that the WWSP has caused material Stateline depletions. Kansas' case has not been helped by its own contradictions in quantifying impacts to usable flow – ranging during this trial from 255,000 acre-feet initially, to 44,000, to 40,000; nor by the fact that depletions are essentially eliminated if accretions are taken into account. This is not to say that the WWSP has not adversely impacted Stateline flows, but rather that Kansas has failed to prove that it has.

SECTION XXIII

RECOMMENDATIONS

The trial in this case was bifurcated into a liability and a remedy phase. This Report presents my recommendations on the issue of liability with respect to the various claims of the states.

The major issue in the trial, and in Part I of this Report, is whether postcompact well pumping in Colorado has violated Article IV-D of the Arkansas River Compact. I recommend that the Court find that such a violation has occurred, and that Kansas prevail on this issue. With respect to Kansas' additional claim concerning the Winter Water Storage Program, I recommend that the Court find that Kansas has failed to prove that operation of the program has violated the compact.

Four other liability issues were decided on motion, either before the trial began or after evidence was received. With respect to these issues, I recommend that the following decisions be confirmed:

(a) Granting Colorado's motion for partial summary judgment on the legal issue of whether the Winter Water Storage Program in Pueblo Reservoir was subject to the approval of the Arkansas River Compact Administration. This decision is Part II of this Report.

(b) Granting Colorado's motion to dismiss the Kansas claim arising from the operation of Trinidad Reservoir. This decision is Part III of this Report.

(c) Granting Kansas' motion to dismiss Colorado's "Lake McKinney Counterclaim." This decision is Part IV of this Report.

(d) Granting Kansas' motion to dismiss Colorado's "Well Counterclaim." This decision is Part V of this Report.

If the Court finds, in accord with this Report or otherwise, that the Arkansas River Compact has been violated, then I recommend that the case be remanded for further evidence and conclusion of the remedy phase of the trial.

DATED: July 1994 Respectfully Submitted,

ARTHUR L. LITTLEWORTH,
Special Master