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Hydrologic Effects Provoked in Mexican Territory by the Recovery of Infiltrated Water in the "All American Canal" in California, United States of America.

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I. Background

The Government of the United States of America seeks to construct in the Imperial Valley, California, in the outskirts of its international boundary with Mexico, a canal that will replace a section of the All American Canal (AAC), with the objective of recovering a fraction of the volume of water that is lost there through seepage. For that reason, it has presented the corresponding project for the Mexican Government's consideration, through the International Boundary and Water Commission (IBWC) between the United States and Mexico, in compliance with that established in point No. 6 of Commission Minute 242, with respect to the obligation for consultation prior to the realization of any development or work that would generate adverse transboundary effects.

This present document, elaborated at the Groundwater Department of the National Water Commission (CNA) - General Technical Office, evaluates the probable effects that the referenced work could have on Mexican territory.

II. The All American Canal Project

The AAC is located in the southern border of the State of California and conveys water derived from the Colorado River for agricultural use in the Imperial and Coachella Valley Irrigation Districts to which it supplies an average annual volume of 3,453 hectometers cubed (see Fig. No. 1). It has a length of approximately 132 km, from its origin at Imperial Dam through its lower end, located about 15 km east of the city of Mexicali, Mexico; its width varies along its path from between 46 and 61 m; its depth is from 2 to 6 m; its topographic depression in all the distance traveled is 53 m (see Fig. No. 2).

The canal's capacity from Imperial Dam through the hydroelectric dam siphon is 49 m^3/s; between this dam and the point named Pilot Knob, 372 m^3/s, and from Pilot Knob to gradient No. 4, 287 m^3/s. The AAC crosses through a dune zone in a

section 48 km in length between Pilot Knob and Gradient No. 4, in outskirts of the international boundary. Four steps denominated as gradients exist in this section in which electrical power is generated, with distances between them as follows: from Pilot Knob to Gradient No. 1, 22.4 km; from Gradient No. 1 to No. 2, 8.4 km; from Gradient No. 2 to No. 3, 8.7 km; and from Gradient No. 3 to No. 4, 8.5 km.

In November 1989, the United States Congress authorized the Lining of the All American Canal (AAC) project and a portion of the Coachella Canal, with the purpose of recovering part of the volumes of water that are lost due to the filtration along them and to transfer the recovered water to the Metropolitan Water District of California. On September 11, 1990, in an IBWC session, specialists of the U.S. Bureau of Reclamation presented to the Mexican delegation the original version of the referenced project that consisted on the lining of the section of the AAC situated between Pilot Knob and the Gradient No. 4. In the following years, several modifications to the original project were contemplated; finally, within the IBWC, a United States delegation presented the last version of the project in the following terms:

Due to the increasing necessity of water in southern California and the insufficient availability of the resource, various diverse water conservation projects have been undertaken, among which includes a partial recovery of the volumes of water lost through seepage in the Imperial Valley irrigation district, mainly in the AAC.

Specifically, the current project consists of the construction of a lined canal of 37 km in length, parallel to the current AAC in its section beginning one mile west of Pilot Knob to Gradient No. 3, which is expected to recover close to 84 hm^3 per year, a volume that represents approximately 80% of the total loss (it is estimated that 20% of the same will continue to filter in the canal after its construction). The United States Government has budgeted approximately $235 Million Dollars (U.S.-Dollars) for construction of this work. The executive project was concluded in 2004; the construction work is scheduled to begin by the middle of 2005, and start its operation in 2008.

As a result of the studies done to determine the hydrologic and environmental impact of the new canal, it is concluded that the principal effects would be:

i) Lowering of the subsurface levels in the AAC zone of influence at a rate that will depend on the magnitude of the exploitation of the Mexicali Valley aquifer, and

ii) vanishing of a large part of the native vegetation that grows along the lower section of the canal.

III. The All American Canal Project

The aquifer named "Mexicali Valley" ("*Valle de Mexicali*") extends in the Mexican portion of the lower basin of the Colorado River, in the state of Sonora. In the present document, only the northeast portion of the Mexicali Valley and the Mesa de Andrade is considered because of its proximity to the AAC.

Within the area of consideration, the aquifer has great density that increases from the border toward the central-eastern portion of the valley, where the exploratory wells have cut up to 800 m of filler without reaching the foundation (see Fig. No 3). Its hydraulic characteristics vary in the area depending on the granulometry and density of the alluvial filling; generally, the transfer and storage coefficient values are higher in the northeast portion of the valley, where unconsolidated material of thick particles deposited in the river delta predominate, and gradually decrease toward the west and south, accordingly the proportion of fine sediment increases in the filling (see Fig. No 4). Particularly, in the area of major interest, the transfer varies in the range of 0.005 to 0.15 m^2/s, and the storage coefficient, between 0.15 and 0.3 (see Figs. Nos. 5, 6, and 7).

The natural recharge of the aquifer, contributed by the Colorado River and infiltration from seepage in the mountainous sides, is insignificant with respect to

the volumes of water currently utilized, due to the reduced rainfall and the elevated evaporation potential of the region. Agricultural development on both sides of the international border has substantially increased the restoration of groundwater: losses in long canals, wide sections and very permeable beds, the seepage of irrigation exceedances in lands with large infiltration capacity, and the intense exploitation of the aquifer, have led to substantial maintenance.

One of these recharge sources is the AAC located on the southern border of the Imperial Valley and in the outskirts of the international border. Since its operation started in 1939, its losses through seepage led to the formation of a dome in the subsurface area, generating a large part of the underground sustenance that the Mexicali Valley receives from United States territory. According to United States studies provided through IBWC (*CILA*), that canal currently loses about 113 hm^3/a in the section that is projected for substitution, estimating that close to 90% of that volume of water enters Mexico underground.

Since the 1950 decade, measurements have been taken of the depth of the groundwater levels in wells spread throughout the Mexicali Valley and the San Luis Colorado River mesa. The configurations of the water levels corresponding to different dates clearly show the underground sustenance that the Mexicali Valley receives through its northern border (see Fig. Nos. 8, 9, 10, and 11). The volume of underground flow, calculated by applying Darcy's law to a section of flow close to the international border, parallel to the same and of a width similar to the length of the AAC referenced section, results in some 80 to 90 hm^3/a, a statistic that agrees in order of size, with the estimate of the amount of water filtrated in the AAC which migrates toward Mexican territory (the range considered is due to the uncertainty of the transfer values and the hydraulic gradient). These configurations and those corresponding to the Imperial Valley are in reasonable agreement as far as the elevations of the groundwater levels along the border zone, and considered together confirm that the underground sustenance that enters the Mexicali Valley through its northern border originates in the AAC (see Fig. No. 12).

In the Mexicali Valley, fluctuations in the piezometric levels have been recorded, caused by variations in the size and distribution of the recharge of the aquifer, from the extraction of groundwater and the volumes of surface waters delivered to Mexico (see Figs. Nos. 13 and 14); logically, in the years that large quantities of surface water were received, the extraction of groundwater was less and the recharge of the aquifer was higher. Likewise, progressive decreases were recorded in the 1953-79 timeframe, with maximum values of about 7 m in the central portion of the valley, which represents the transient state generated by the start of extraction of groundwater at a larger scale, which provoked the lateral propagation of its effects toward the natural recharge and discharge areas. Later, in the 1980-86 timeframe, the increase in the piezometric levels was recorded, which is attributed to significant exceedances of surface waters that were received from the United States of America, and, for the same, that the extractions of groundwater lessened with respect to the prior timeframe. In the 1987-2004 interval, the volumes of surface water and the extractions of groundwater were more or less uniform; consequently, the piezometric levels presented lesser fluctuations, but conserved approximately the same average level. In the long run, in the 1953-2004 interval, the average groundwater level in the Mexicali Valley decreased from 2 to 4 m.

According to information published in U.S. Bureau of Reclamation reports, the filtrations in the AAC formed a "dome" in the subsurface area: during the 1939-72 interval, the subsurface levels increased up to 15 m in the southern portion of the Imperial Valley, under the canal, and from 1 to 11 m in an area of influence that is extended in Mexican territory, up to some 15 km south of the international border (see Fig. No. 15). This "dome" started to form in 1939, the year in which operation of the AAC started, and probably stabilized in the course of the 1950 decade, when the hydraulic gradient was generated enough to transmit the volume filtered in the AAC: the piezometric observations realized in the Mexicali Valley, in that decade,

in the wells closest to the international border, suggest that by then the "dome" was already stabilized.

Currently, CNA operates an aquifer piezometric monitoring system, which includes 38 wells spread out in the probable area of influence of the AAC project, which consists of the Mesa de Andrade and the northeast portion of the Mexicali Valley. During 2005, automatic probes will be installed in 10 of them to record the variations of subsurface levels in that area with higher frequency (see Fig. No. 16 and Appendix I). Additionally, two hydrometric control stations installed in the La Mesa Drain will be relied on.

III. THE "LA MESA" DRAIN

Piezometric observations done in 2004 reveal that the subsurface area is very shallow in the Mexicali Valley largely due to the incidental recharge generated by the irrigation exceedances and the losses in the irrigation district canal system: the depth of the subsurface levels vary between 2 and 10 m in the valley, and between 4 and 7 m in the Mesa de Andrade, that was raised several meters above the level of the valley. Along the base of the Mesa de Andrade, the subsurface area outcrops in the La Mesa drain, constructed in 1960 with the objective of recovering flooded lands. An N-S piezometric profile indicates that the difference in hydraulic charge between the AAC and the La Mesa drain is about 12 m (see Fig. No. 17).

Variation in water quantity and salinity along the La Mesa drain is derived through measurements and conclusions of electrical conductivity and water salinity (see Fig. No. 18). Thereby, it is known that the drain receives close to 2,000 lps, with the spatial distribution as follows: 4000 lps discharged by various lateral drains, and 1600 lps contributed directly from groundwater. Around 60% of this last amount enters in the first 15 km of the drain from its upper limit (see Fig. No. 19). The salinity of the water conveyed through the drain increases gradually toward waters below, from 900 ppm in its upper section, to a little more than 2,000

at kilometer 38 of its development; waters below this site, the salt content continues to increase, although in an irregular way because of the contributions and derivations, reaching values close to 3,500 ppm. The water discharged through the tributary drains, very shallow, has salinity of 1,200 to 4,400 ppm and is a product of the irrigation returns that flow underground without entering the aquifer (see Fig. No. 20).

From the balance of salts dissolved in the water from La Mesa drain, it's deduced that its volume is composed of about 1,000 lps proceeding from the AAC, with average salinity of 900 ppm, and about 1,000 lps arising from irrigation returns from the Mexicali Valley, with average salinity of 3,500 ppm. The larger gain of water with low salinity in the upper section of the drain is attributed to the highest permeability found in that area of the aquifer, and to the conditions that most favor filtration in the AAC: according to studies done by the U.S. Bureau of Reclamation in the section between the Pilot Knob and Gradient 2 sites, the subsurface area is not connected hydraulically to the AAC, a condition corresponding to the maximum hydraulic gradient caused by the losses at this point. On the contrary, the direct hydraulic connection between the canal and the aquifer exists in the section Gradient 2 – Gradient 4 due to which the loss is less than in the first section. At the same time, such hydraulic conditions are related in part with the hydraulic characteristics of the aquifer: the large transmitting capacity of the deposits in the upper section area permits the rapid dispersion of the filtrated water, with a lower hydraulic gradient by which the "dome" did not reach the base of the canal.

The water collected by the La Mesa drain is derived for irrigation through ditches, the most important located at kilometer 40 captures 800 lps, and numerous pumps installed along the drain that together extract an additional 200 lps (see Fig. No 21). The total volume derived, about 1,000 lps, is utilized for irrigation of 1,200 ha, in benefit to 60 agriculturers that do not receive water from the district.

To the volume of water that outcrops in the drain, one must add that which escapes to the atmosphere through evaporation and evapotranspiration in a wide area of wetlands and natural vegetation developed along the drain – "*tule*" and other species – that has an extension of approximately 120,000 m^2 and where an important ecosystem that accommodates various species of flora and fauna has formed. Other minor outlets, although not quantified, are those that correspond to evapotranspiration that occur in wetlands located above the origin of the drain and to the recharge induced from the same through wells localized in its proximities. Altogether, these outlets are estimated at about 2 hm^3/a.

Based on the aforementioned and accepting the information presented by the U.S. Bureau of Reclamation, the filtrations from the AAC are distributed as follows (see Fig. No. 22a). Of the total loss of 113 hm^3/a in the section considered, approximately 5 hm^3/a are captured by the natural vegetation that grows in the margins of that canal and 10 hm^3/a are incorporated in the aquifer; 10% (11 hm^3/a) of this volume of water flows toward the Imperial Valley and the remaining 90% (97 hm^3/a) migrates toward the Mexicali Valley. This unequal distribution between both sides of the border is due to intensive surface water irrigation in the Imperial Valley and the extraction of groundwater is comparatively insignificant: consequently, the subsurface area is very shallow, limiting the flow gradient that the AAC induces toward the north. Of the 97 hm^3/a that enter Mexican territory, some 35 hm^3/a outcrop in the La Mesa drain and outskirts, and the other 60 hm^3/a are transferred through the aquifer toward the south.

The distribution of filtrated water in the section of the AAC that is projected for substitution with the new version of the project is the following (see Fig. No. 22b). Of the total loss of 84 hm^3/a in the section that will be substituted, approximately 4 hm^3/a are captured by the natural vegetation that grows in the margins of that canal and 80 hm^3/a are incorporated into the aquifer; 10% (8 hm^3/a) of this volume of water flows toward the Imperial Valley and the remaining 90% (72 hm^3/a) migrates toward the Mexicali Valley.

IV. IMPACTS OF THE CONSTRUCTION OF THE NEW CANAL

Based on available information, the probable effects caused by the construction of the new canal on Mexican territory were analyzed. For that purpose, the model named "Visual Modflow" was used, finite differences, originally developed with the principal objective of analyzing different options of managing the Mexicali Valley aquifer. The adapted model includes the northeastern portion of the Mexicali Valley, the northwest section of the San Luis Mesa, the Mesa de Andrade, and the southern border of the Imperial Valley. Its northern limit coincides with the approximate line of the AAC, considered as a sustenance border.

The model was calibrated paying special attention to the northern half of the considered area and the parameters were adjusted to reproduce the growth of the dome created by the AAC. The magnitude of the losses at this point was fixed based on the data that were provided at the IBWC (*CILA*) meeting held on September 11, 1990, and those documented in the Bureau of Reclamation Reports (1994). Once the model was calibrated, it was applied to predict the decline of the "dome" in Mexican territory after the construction of the new canal, if the filtration in the AAC was reduced by 25% of its current volume – according to summary of the project provided by the U.S.IBWC delegation, seeks to recover close to 75% of the quantity that currently filtrates, with which the underground flow that passes to the Mexicali Valley proceeding from the AAC will be reduced by 72 hm^3/a (see Fig. No. 23 and 24).

The results of the analysis reveal the decline of the "dome" throughout time. The reductions would increase in Mexican territory with decreasing magnitudes toward the south, reaching values of 6, 10, and 12 m in the outskirts of the international border, for 3, 5 and 10 years after the lining, respectively. For the same periods, the influence would extend to distances of 4, 8 and 11 km,

respectively, to the south of the boundary line. Within this area of influence, the decrease provoked by the lining of the AAC would be superposed with that provoked by the exploitation of the Mexicali Valley aquifer: the results of the simulation indicate that the first would be of great magnitude and the second in a time frame of 10 to 15 years counted from the reduction of the filtrations – supposing that the extractions in the Mexicali Valley would be maintained at an average annual volume of 600 hm^3/a – and that its magnitude would decrease in time until it cancels itself at the end of that time frame (see Fig. 25).

These results are compatible with the fact that the "dome" took 15 to 20 years to develop (from the beginning of the operation of the AAC, in 1940, until the stabilization of the subsurface area, in the course of the 1950 decade); it also agrees with the fact that the extraction of a quantity of groundwater similar to the current amount during 15 years barely provoked reductions lower than 4 m in the north portion of the Mexicali Valley.

In turn, the decline of the "dome" would provoke the following collateral effects:

- The discharge of groundwater to the Mexicali Valley aquifer would be reduced by approximately 70 hm^3/a, a quantity equivalent to the flow that would stop entering through the northern border.
- The suspension of this sustenance of sweet water in the northern portion of the Mexicali Valley would accelerate the growing trend of the salinity of the groundwater provoked by the infiltration of irrigation exceedances. The historical records of the salinity of groundwater in the Mexicali Valley show that the lower concentrations of that parameter are presented in the zones of influence of the AAC (see Fig. No. 26 and Appendix B).
- In the short term, the contribution of water proceeding from the AAC to the La Mesa drain and the adjacent wetlands would be nullified (see Fig. No 27). As a consequence of this effect, 1,200 ha for irrigation and the remaining volume in that drain would stop benefiting directly, caused by

the irrigation returns, and would stop being usable for agriculture because of its elevated salinity.

- The pumping levels of the wells placed within the area of influence of the AAC would be various meters lower than the current levels with resulting increases in the cost of its consumption of electrical power. The number of affected wells and the additional respective reduction, after timeframes of 3, 5, and 10 years counted with the beginning of the lining, would be 30, 70, and 90, respectively (see Fig. No. 24). Generally, the affected wells provide volumes higher than 50 lps with reduction less than 5 m, thanks to the great transfer of the aquifer; therefore, in many of them, the additional reduction would be the same or less than that provoked by its own operation.

V. CONCLUSIONS

6.1. The filtrations in the AAC constitute a recharge source of groundwater that, from the beginning of its operation, has contributed a sustenance of 90-100 hm^3/a to the Mexicali Valley aquifer.

6.2 The construction of the canal will replace a section of the current AAC, will reduce the filtration by 75%, and with that, will reduce the underground flow that the Imperial Valley contributes to Mexican territory in approximately the same amount.

6.3 The construction of the canal will provoke the decline of the "dome" formed in the subsurface area by the filtrations along its course, provoking reductions in the piezometric levels of the aquifer in Mexican territory. During the following 10 to 15 years counted from the beginning of the operation of the new canal, these reductions will have decreasing values from north to south, with a maximum value at about 12 m south of the international border.

6.4 In turn, the decline of the "dome" in the levels of groundwater will mean:

i) The elimination of the volume of some 1,000 lps that the La Mesa drain receives from the AAC, and, with that, the loss of approximately 1,200 ha that are currently irrigated with water from that drain;

ii) The reduction of the output from the wells within the area of influence of the lining, with the resulting increase in its cost of operation;

iii) The increase in the growing trend of the salinity of groundwater in the north portion of the Mexicali Valley;

iv) The vanishing of the wetlands adjacent to the La Mesa drain and of the ecosystem that is accommodated by the wetlands.