Water Resources Commission

NEW SOUTH WALES

"SALINITY CONTROL IN THE U.S.A."

Report of a study and
inspection tour
JULY 1983.

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1. INTRODUCTION:

Salinity of the soil resource of irrigated lands in the Riverine Plain has been a problem for some time in the Wakool Irrigation District, but not in most of the other Irrigation Areas and Districts of NSW. However, recently development of high water tables and associated salinity is becoming more widespread, increasing concern in the community.

The Water Resources Commission, by its Research Branch, has the objective of trying to understand the processes at work, and to quantify the various parameters, so that suitable solutions to the developing problem may be defined and implemented. An example of such a solution is the Wakool - Tullakool Sub-surface Drainage Scheme, which became operative during early 1982.

An international symposium, organised by a number of U.S.A. agencies active in the field of salinity control, appeared a suitable forum to exchange some of the New South Wales experiences with others. A paper entitled, "Salinity control problems associated with irrigation in South West New South Wales" was prepared by Mr. S.E. Flint, Principal Research Officer and myself, and presented by the latter.

This conference, held at Salt Lake City, Utah, from 13th to 15th July, 1983 was followed by a post conference tour to visit centres active in salinity control problems. Centres visited are shown at figure 1. Special attention was given to criteria that are used for design of sub-surface drainage systems, and the implementation of the various options available for effluent disposal.

In addition the role of modelling in the understanding of these processes was looked at and discussed whenever possible.

Sections on drainage criteria and effluent disposal in this report focus on the objectives on basis of which this tour was approved and financed. These sections are preceded by a section giving background information relevant to drainage in four irrigation districts visited. A summary of conference findings and a chronological account of the trip are attached for completeness.

The author is indebted to the Government of NSW for promoting the opportunity to enhance his knowledge on salinity control problems and related subjects in the USA. He is also indebted to the Rice Industry of NSW who by means of the Rice Co-ordination Committee sponsored the cost of air transport during this trip.

A. van der Lelij,
17th August, 1983.

2. BACKGROUND INFORMATION ON DRAINAGE PROBLEMS IN IRRIGATION DISTRICTS.

2.1 Grand Valley Irrigation District.

Reference: Conference papers 17, 27, 28.

2.1.1 Location:

The Grand Valley is located in central west Colorado along the reach of the Colorado River between Palissade and Mack, and includes Grand Junction, the largest city in western Colorado (30,000 inhabitants). See Figure 3.

2.1.2 Type of Farming:

Tree crops are abundant in the east, but to the west growing of lucerne or other fodder grains (sorghum, maize) dominates. Farm size varies from 10-100 hectares, increasing to the west. The owners of many of the smaller farms have additional employment to support themselves.

2.1.3 Irrigation System.

The irrigated areas total about 28,500 hectares. There are private schemes, supplied through the Grand Valley Canal, and a Government Scheme, supplied through the Hiline Canal. Diversions are always in excess of demand, particularly in the private scheme, where the channel runs full board all season, with spill of any excess back to the Colorado. Irrigation water is available practically on demand.

The land slopes at an average 2% from north to south. Irrigation is by border check or furrow. Wasteful practices and canal seepage have created a groundwater mound. Apart from waterlogging and salinity symptoms in about one third of the area this is causing a contribution of 530,000 Mg of salt to the Colorado, by process of seepage through the Mancos shale, whichunderlies the District at depth greater than 5 - 10 metres.

Of a typical annual deliveryof 840,000 Ml to the District about 10% results in seepage to the groundwater table and 30% back to the river. In the low demand season up to 80% of diverted water may be spilled.

2.1.4 Hydrogeological.

The Mancos shale is high in gypsum and sodium sulphate salts. The uppermost layers of this very thick formation have the highest transmissivity of 4 - 540 m^2/day. An unconsolidated "cobble aquifer" traverses the landscape at shallow depth, adding to the complexity of the hydrology. This, and uneven topography make the compilation of groundwater contour maps impractical.

Soils are sandy to loams and appear to be colluvial. A soil called Billing clay is derived from the Mancos shale.

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Some tile drainage is installed in the high watertable areas. Effluent has an average salinity of about 4,400 mg/L but in some observation bores salinities up to 30,000 mg/L have been measured. There does not seem to be any control over the installation of additional tile drainage.

2.1.5 Plan.

Studies for the overall Grand Valley area indicate that the 530,000 Mg annual salt load to the river could be reduced by decreasing the amount of irrigation return flows and conveyance system seepage. A decrease in the salinity at Imperial Dam could be accomplished by a two segment programme by the Bureau of Reclamation and the Soil Conservation Service of the Department of Agriculture. The Bureau is improving the off-farm system by concrete lining of channels and construction of automated upstream level control structures whilst the Soil Conservation Service supervises on-farm programmes.

The on-farm measures include level ported concrete lined ditches, automated gated piping, Sideroll sprinkler systems and cablegation to improve irrigation efficiency. In the Government Scheme 75% is funded by the Government, the farmer contributing 25%. Revenues from power generation in the Colorado river contribute to the Government's share.

2.1.6 Status

Stage I covering about 10% of the District, has been completed at a cost of US$9 million. Stage II, to complete 80% of the District, is estimated at US $160 million. It is hoped that for this cost the salt load to the river will be reduced by 370,000 Mg/year, or 41 mg/L at Imperial Dam. Monitoring is being carried out to determine the benefits of the Stage I construction.

2.1.7 Impressions.

The value of irrigated agriculture of this District is not particularly impressive, farms being small and used mostly for production of feed for beef cattle, which is in a depressed state at present.

The seepage from channels and over irrigation obviously caused problems of waterlogging and salting and increased salinity to the river. However, to me it appeared that an improvement of on-farm irrigation efficiency to 70 - 80% and a virtual removal of channel seepage as a factor may not reduce the seepage into the river by 71%, as claimed. All deep percolation would either seep to the river, adding to its salt load, or evaporate after capillary rise from a watertable in the lower areas of the valley. It may be that the scheme will result in a reduction of the latter factor, leaving the seepage component to the river at a relatively higher level.

2.2 Wellton-Mohawk Irrigation District.

Reference, Conference papers 36, 41.

2.2.1 Location.

The Wellton-Mohawk Irrigation District is located in south western Arizona along the Gila River, about 20 - 100 km east of Yuma. The town of Wellton is the District headquarters (Figure 4).

2.2.2 Type of Farming.

Whilst lucerne production and other field crops dominate, there is also irrigation of cotton and vegetables such as lettuce and melons. Citrus production has been halved in recent years, some land having been bought out by the Federal Government. The total irrigated area of the District now is 26,300 hectares.

2.2.3 Irrigation Systems.

Water rights to the District are expressed as net delivery, being water diverted from Imperial Dam through a canal and syphon under the Gila River minus any drainage flows. The drainage flow is mostly tubewell effluent with an average salinity of 3200 mg/L. The water rights are 370,000 ML, during 1982 about 500,000 ML was diverted and 140,000 ML was returned to the Wellton Mohawk drainage channel.

Whilst diversions have decreased from about 620,000 ML during the early seventies to present levels, the drainage component has decreased by a larger percentage, from about 250,000 ML to present levels. This is due to improved irrigation practices and extensive concrete lining of channels, supported by Bureau of Reclamation and Soil Conservation Service Schemes.

Channel losses are in the order of 8% and on-farm irrigation efficiency in the order of 60-65%. Farms are mostly large, there being only 125 farms producing a gross return of $75 million.

Most of the land is laid out to level basin irrigation. The size of the bays, usually 180 by 90 metres, wide, depends on soil variability, infiltration characteristics and soil water holding capacity. Water is measured with long throated and broad crested flumes installed in concrete channels. Flows of 30 - 40 ML/day into bays are common. By using such large flows a bay is filled up quickly to the required application rate, then the water is allowed to soak into the ground.

The farmer reads the gauge near the flume, then derives from a chart the time needed to divert a certain application rate into a bay, then opens ports in the concrete channel manually or sets time clocks on automated structures downstream.

2.2.4 Hydrogeological.

The irrigated landscape consists of valley soils and the Mesa lands. The latter are elevated by several metres and usually lighter in texture and more permeable. The whole area appears to be underlain by coarse gravelly aquifers of thickness 12 - 15 metres. Tubewells extending to 30 metres depth into this aquifer lift groundwater into the drainage system to reduce watertable levels.

The salinity of individual tubewells (110 in all) varies from about 1000 to 7000 mg/L, the average being 3200 mg/L during recent years, having declined from about 5700 mg/L during 1962 and 4000 mg/L during 1970 to present levels. A further decline is unlikely, considering an irrigation water quality of about 850 mg/L and an aimed for irrigation efficiency of 70 - 80%.

It is interesting to note that a flood in the Gila River during 1979 scoured a channel up to 4 metres deep in its bed. This is causing groundwater seepage into the river, reducing the drainage return flow from groundwater pumping. The District is now trying to get credit for these seepage flows to be able to meet the net 370,000 ML maximum water right requirement in the future.

2.2.5 Status.

Progress with on-farm measures to reduce accessions to the watertable are well underway. The Soil Conservation Service is designing and implementing on-farm projects which are 75% subsidised through the Bureau of Reclamation. (NB. the 75% subsidy dues become taxable for the farmer eventually as a capital gains tax). Eventually it is hoped that 70% efficiency can be obtained on the Mesa lands and 80% on the valley soils.

The Wellton Mohawk Scheme is a Title I project under the 1974 legislation supporting the treaty to secure water quality to Mexico (879 mg/L at Imperial Dam + 115 mg/L $\pm$ 30 mg/L at Morelos Dam). Since it was considered unacceptable to waste the 140,000 ML drainage flow from the Wellton Mohawk Scheme in an already overcommitted Colorado River, this legislation also provided for the construction of a 129,000 ML/Year desalting plant at Yuma, at a cost of $225 million or approximately $250/ML reclaimed water (1979 estimates). Whilst uneconomic as such, this scheme is still going ahead. Ironically, a flood in the Colorado river during 1983 wiped out any shortfalls that existed at Hoover Dam with regard to water book keeping of deliveries to Mexico.

2.2.6 Impressions.

The Wellton Mohawk Scheme is rather impressive as far as the level of agricultural activity is concerned. Farms appear to be efficiently run. The irrigation system has been modernised.

The method of calculating water rights as the difference between diverted quantity and drained quantity does not provide an incentive for high efficiency. Some incentive lies with the cost of operation of the tubewells which is not insignificant.

Because of the commitment to reclaim the drainage water and the high cost thereof, part of the Title I project has been to buy back from farmers 1500 hectares of citrus from which deep percolation was particularly excessive. Such buying up of land is cheaper than operation of the desalting plant, yet perhaps this should not be evaluated on agricultural economic factors alone, since a considerable multiplier factor operates with the rest of the community.

Tubewell drainage in this district is the cheapest way to drain high watertable conditions. Some evaluation of tubewell operating times in relation to groundwater contour maps is being made.

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2.3 Imperial Irrigation District.

2.3.1 Location:

The Imperial Irrigation District is located in southern California. El Centro and Brawley are the major towns (Figure 5).

2.3.2 Type of Farming.

Of the total 400,000 hectares within the District, about 193,000 hectares are classified as farmable. On this about 243,000 hectares of crops are grown each year, including double cropping practices. Major vegetable crops are lettuce(12,000 ha), Onions (4,000 ha) carrots and melons (9800 ha). Lucerne (81,000 ha), cotton (17,000) and sugar beets (15,000 ha) are major field crops.

The climate is arid and hot and many crops are grown from Autumn to Spring, rather than during Summer. Irrigation water is supplied through the All American Canal from the Imperial Dam. The water rights to the District amount to 3.2 Million ML/year. About 7000 water accounts are being kept by the District for about 4,000 farmers.

2.3.3 Irrigation and Drainage System.

Water released at Imperial Dam into the All American Canal may arrive about 24 hours later at the farm gate in the southern part of the District and several hours later in the northern end (See Figure 6). Automated radial gates in main canals adjust flow rates periodically to match water orders by farmers and travel times as closely as possible.

Several small en-route storages (about 25 ha. size) provide buffer capacity. It was claimed by the management of the District that spills at the end of channels are as little as 2%.

Farmers take orders on a 24 hour basis, cutting off of flows and starting up at odd hours not being permitted. This no doubt enhances the efficiency of the Districts system but makes it more likely that farmers have increased surface drainage at times.

The land is laid out to border check and furrow irrigation with some slope in the layout, which contrasts with the Wellton Mohawk Scheme, where level basin irrigation is being practised. Depending on soil type and slope, a variable proportion of farm diversion may result in surface runoff, the average probably being about 10% or slightly above.

All drainage, including subsoil drainage, ends up in Salton Sea, a waterbody of some 1000 km^2, elevation - 70 metres. About one third of all diversions are drained, meaning that about 20% of drainage flows may be subsurface drainage flows.

A 21 point water conservation programme was introduced during 1980 to reduce the quantity of runoff from farms. This was necessary since Salton Sea levels have risen, causing damage to on-shore property. Penalties are imposed on landholders if on two consecutive occasions the measured drainage flow exceeds 15% of delivery to a farmer.

During 1982 a total of 41,000 field discharges were checked, of which 6,117 were in excess of 15% and 1670 after the second check.

Investments in recent years have been aimed at improving efficiency, by concrete lining of channels, installation of measuring flumes, automated control structures and concrete boxes for measuring drainage flows.

2.3.4. Hydrogeological.

Soils vary from light in texture to fairly heavy. Most are alkaline with PH in excess of 7, containing various amounts of sodium and calcium salts (mostly sulphates). Soil permeability varies accordingly. Due to the method of deposition from the Colorado river during floods there is stratigraphical layering of sandy lenses and clayey deposits at most locations. To the east and west aeolian deposits are common.

Problems with waterlogging and salinity were common in the past but tile drainage in about 173,000 hectares of land has maintained productivity throughout the District. Spacing varies from 12 to 60 metres and depth from 1.3 to 2.7 metres, with an average depth of 1.8 metres. Effluent is pumped or flows by gravity into open drains flowing into the New and Alamo Rivers, which drain into Salton Sea.

Almost 3 million Mg of salt is brought into the area each year with irrigation water (salinity 850 Mg/L approx) and 4.4 million Mg removed through drainage, giving a favourable salt balance for the District. Tile drainage effluent salinity averages 5,000 mg/L and the combined drainage flow about 4,000 Mg/L, confirming that the subsurface component is the most signficant.

2.3.5 Status.

Concrete lining of District channels is continuing as funds permit. Farmers adjacent to laterals pay 30% and the District the remaining 70%. There is no federal funding for this programme.

A law suit against the District for damages because of increasing levels of Salton Sea was lost by the District, but the matter is under appeal.

Restrictions on subsoil drainage quantity have not been considered to date. The aim is to keep watertables well below the root zone. An irrigation scheduling service is operated by the District in conjunction with the Soil Conservation Service, using neutron probes. Such a service is aimed at reducing soil percolation rates by more efficient management. However, since water is relatively cheap (about US $7/ML) there is reluctance on behalf of farmers to pay the annual US$12.50/ha. fee.

Experiments are underway by the U.S.D.A. Salinity Laboratory at Riverside to reuse drainage water for irrigation of cotton. This has proved successful to date provided germination irrigations are carried out using fresher channel supplies.

2.3.6 Impressions.

This District would be the most productive District served by waters of the Colorado River. Farm prices however have not been good in recent years, affecting the Districts economy.

The decision by the Court against the District may or may not be upheld. Whatever the outcome may be, the onus seems to be on the farmers, rather than the District to reduce drainage rates, both surface and subsurface.

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There seems to be scope to reuse a proportion of drainage flows using alt tolerant crops. The water so saved in terms of diversions to the istrict could be leased at favourable rates to the city of Los Angeles, nich seeks to obtain additional water supplies. This proposition exists it has so far not been found acceptable.

.4 San Joaquin Valley, California.

2.4.1 Location.

The San Joaquin valley is located in central California, east of an Francisco, extending south to Bakersfield, which is about 150 km orth of Los Angeles. The valley is enclosed by the Sierra Nevada to he east and the Coastal ranges to the west (Figure 7).

Attention was given to areas at risk of salting, which are located est of and south west of Fresno.

2.4.2 Type of Farming.

Rice growing may be found in the north, near Sacramento. The area rom Bakersfield to Fresno irrigates a large diversity of crops, including rapevines, citrus, vegetables, cotton, lucerne, avocadoes etc. This region ithout a doubt is the richest irrigated area within the U.S.A., comprising 1.2 million hectares.

2.4.3 Irrigation System.

In the southern part of the Valley groundwater pumping provides ater for about 80% of irrigation needs. These bores are installed to lepths of 600 metres and usually equipped with Layne and Bowler type vertical haft multiple stage pumps. Lifts of 6 – 100 metres are common, but do each 180 metres in places. Locations with very high pumping lifts tend o have become less economical for irrigation production in recent years.

To the west of the valley pumping from the San Joaquin and Kings livers provide a supply as well as diversions from the California aquaduct, hich runs all the way from the San Francisco Bay area to Los Angeles and eyond, is concrete lined, and includes pumps to lift water across mountains s well as en route reservoirs (e.g. San Luis Reservoir).

Several irrigation districts, such as Westlands Irrigation District W.I.D.) west of Fresno and Tulare Lake Irrigation District (T.L.I.D.) receive ater from the aquaduct.

Irrigation methods vary, furrow irrigation and border check irrigation eing common. In the T.L.I.D. water is lifted by huge caterpillar engine lriven pumps from centre ditches into border checks, which may have lengths of 1500 metres and grow cotton.

2.4.4. Hydrogeological.

The deep alluvial sediments of the valley tend to be loamy to the east, where sediments are associated with the granitic outcrops of the Sierra Nevada and more clayey to the west, because of the location of drainage lines and the nearby sedimentary formations of the coastal range. Clay minerals are predominantly kaolinitic to the east and montmorillionitic to the west.

Extensive aquifers occur, particularly in association with the Kings and San Joaquin River Systems, which traverse the valley from east to west. Transmissivity is high and recharge from these rivers to the aquifers seems to almost match the withdrawal rates by groundwater pumping, except at mid points between river systems, where a declining pressure level has been observed.

A groundwater model for the valley has been developed to predict future trends as far as the groundwater resource is concerned.

In the western part of the valley a near impermeable clay layer, called Corcoran clay, occurs at depth of 15 - 30 metres in the south and 120- 150 metres west of Fresno, in the Westlands Irrigation District. It has a thickness of 6 - 21 metres and provides a barrier on which perched watertables develop after irrigation. This lake bed deposit is said to have a permeability of 30 mm/year.

This and the relative elevation of this part of the valley have caused groundwater tables to come at dangerously high levels causing potential for salinisation in about 160,000 hectare of land. Eventually 400,000 hectares are believed to be at risk (Figure 8).

2.4.5 Drainage Systems.

The San Joaquin River traverses the valley east to west and then turns north towards the Bay of San Francisco. The Kings River, 50 km south of the San Joaquin, traverses the valley and forks, the southern fork going south towards Tulare Lake.

Tulare Lake has been dry in recent times because waters of the Kings River percolate to aquifers or is pumped directly from the stream. A proportion of the Tulare Lake is allocated for drainage. A problem occurs during floods, during 1983 25,000 hectares being flooded despite massive pumping from this lake into the California aquaduct.

Irrigation development of upslope land of the San Luis Unit resulted in complaints of landholders adjacent to and downslope of this area. This ultimately resulted in construction of 132 km segment of the so called San Luis drain, which has since then become part of the planned Valley Drain (figure 7) of length 467 km and running from near Bakersfield all the way to the Sacramento Delta.

This Valley Drain is part of a package of recommendations by the San Joaquim Interagency Drainage Programme, sponsored by the Bureau of Reclamation, the California State Water Resources Control Board and the California Water Resources Department. Its aim is to arrest salting processes and to provide for disposal of effluent. Environmental factors were considered and the Benefit Cost ratio was calculated to be 2 to 1, projected annual benefits being US$92 million.

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2.4.6 Status

Since this proposal (1979) costs have escalated and serious concern has been expressed about the impact of saline effluent on San Francisco Bay. This and lack of funds have caused the project not to proceed for the present.

Self help schemes, including group evaporation basins or on-farm evaporation basins are being implemented until at a future date perhaps the Valley Drain will be constructed. An example of such a scheme is the Tulare Lake Drainage District, where farmers have constructed a system of open mains (25 km) and pipe line (25 km) to dispose tile drain effluent to evaporation areas, presently totalling 1350 hectares (Figure 9).

It is expected that eventually one hectare of evaporation area will be needed for every nine hectares of drained land, evaporation rates being in the order of 1.35 metres/year net.

Many farmers, particularly in the Westlands Irrigation Districts area, have constructed private evaporation ponds on their properties. One such shallow pond, about 1 hectare in size, was visited.

Problems with deep percolation or impact on the environment are expected to be small. Evaporation ponds have a limited lifetime, in the order of 150 years. Eventually a Valley Drain or alternative means of disposal are likely to be necessary.

2.4.7 Impressions.

This is a very fertile valley with progressive farming. Problems occur in 13% of the irrigated lands, which may climb to 23% by the year 2000 and ultimately 33%. This is considered unacceptable but lack of funds and a legal tangle with environmental concerns prevent the solution, being a Valley Drain and associated measures, of becoming adopted at present. Until such time self-help schemes are being implemented, relying solely on the initiative of farmers. No specific assistance is given with these projects but the California Water Resources Department is monitoring various parameters, such as salinities, drainage flows and nutrient loads for modelling purposes to determine trends.

2.4.8 Reference: San Joaquin Valley Interagency Drainage Program, 1979. "Agricultural Drainage and Salt Management in the San Joaquin Valley.".

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3. DRAINAGE CRITERIA.

3.1 Tile Drainage.

It was a distinct impression that in the U.S.A. there is a wide gap between the development of theory on drainage and the field application. This was confirmed by discussions at laboratories and the University of California, Davis and Riverside.

Subsoil tile drainage is widespread in most areas, particularly the Imperial Valley (Section 2.3) where without it the District would no longer exist. An excellent system of book keeping on where and when installations have been constructed is used, but analysis of the procedures to calculate the drainage spacing and depth reveals that they are not more advanced than those used in for instance the Murrumbidgee Irrigation Areas.

Holes are bored and permeability assessed from field textures in layers up to 3.0 metres. From this the spacing is calculated using a modified Hooghoudt equation. Some consideration is given to variations in excess local or external inputs to the groundwater table, by multiplying these as proportions with the net irrigation applications.

In other Irrigation Districts the service to farmers for drainage design appears to be even more rudimentary, soil types or other arbitrary guides being used by the Soil Conservation Service and drainage contractors. In the San Joaquin Valley (Section 2.4) the Soil Conservation Service used to provide a service, but this has now ceased.

The above comments are not meant to demonstrate that tile drainage is not successful in irrigated areas of the U.S.A. It is! The design procedures, however, are mostly empirical, not backed up by the existing theory developed over the last 15 years. Often drains are installed at wide spacings, with more drains put in between if this proves necessary.

In the eastern, more humid states, Prof. R.W. Skaggs of North Carolina University has organised the collation of many data to do with tile drainage, such as climatic conditions, drawdowns, spacings, soil types etc. This information has been put together with available theory to develop a universal model, called DRAINMOD, which may be used to determine the criteria for a given situation.

The DRAINMOD model applies to humid regions and is not usable for irrigated areas without modification. The problem is associated with the soil moisture storage factor above the watertable, which is subject to much more fluctuation in an irrigated situation. Dr. A. Chang, of University of California, Riverside, is working on these factors, apparently with some success. Actually, the procedures explained to me were similar to the ones adopted by myself to evaluate drainage criteria for the Murrumbidgee Irrigation Areas.

Discussion with leading soil physicists created the impression that the complexity of the issue, to develop drainage criteria for irrigated conditions, may prevent an exact result. Especially the variability of soil parameters would require a flexible approach, in which too much refinement is out of place.

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In most of the large area farm situations of the Riverine Plain no leaching requirement is induced by irrigation water quality as such, but the drainage requirement is largely determined by lateral groundwater seepage to areas at risk. In such situations the only requirement is that leaching dominates the upward capillary rise process. Each drainage situation would depend on the local groundwater hydrology, which needs to be evaluated and standard rules are not appropriate.

Dr. Chang's results are similar in that evaluation of his method showed that the upward or downward deep seepage component dominates. After correction for this factor he found he could predict watertable behaviour quite closely.

In the Riverine Plain the seepage factor is probably even more dominant, except in situations with significant irrigation water salinity. This factor will have to be evaluated for individual cases, perhaps by following certain procedures and tile drainage design would have to be partly empirical, dependent on the accuracy of the evaluation.

The quantification of the seepage component requires detailed knowledge of hydraulic conductivity and thickness of the clays, transmissivity of the aquifer (if present) and gradients. The techniques to measure these factors are time consuming and not highly accurate and variability is high. Consequently it has to be concluded that the only practical approach in many parts of the irrigated landscape will be an empirical approach, trying whether something will work in a given situation.

Modelling efforts to describe a variety of conditions are worthwhile. Such an effort could include the aboveparameters to assess the hazard at any point of an irrigated landscape. Possibly the use of time series analysis and other statistical approaches has some application. This was suggested by Dr. D. Nielsen at the University of California, Davis, but the possession of such skills is yet to be acquired.

3.2 Tubewell Drainage.

Tubewell drainage is widespread in the Wellton-Mohawk Irrigation District (Section 2.2). It is installed to lower watertables, preferably to below 2 metres. Groundwater contour maps are evaluated regularly and pumps operated accordingly. Mostly, about 80 of 110 tubewells are operational.

Some thought is given to groundwater salinity. In the past many wells produced fairly saline effluent. By transfer of sites to nearby locations the salinity was often decreased, whilst maintaining the objective of lowering watertables.

Apart from this, tubewells are installed where needed. There is no specific design pattern, such as a triangular grid, for which theory has been developed to calculate overlap of cones of depression in groundwater levels etc.

Tubewells are installed into extensive aquifers by inserting casing. Holes are punched into the side of the casing by the so called Mill's knife. Up to 100 holes are punched having a size of 10 by 50 mm, each capable of delivering 0.3L/Sec. to the Layne and Bowler vertical shaft multiple stage pumps.

After about 10 years of operation these tubewells often tend to become inefficient, discharge dropping to half or less, Ca Co_3 concretions blocking soil pores near the screen and other corrosion problems occurring. The tubewell is then replaced.

Effluent from the tubewells has a salinity averaging 3200 mg/L, some of it being less than 1000 mg/L. All this effluent is being diverted through a concrete lined channel to be desalted by reverse osmosis at Yuma (near future, Section 5.2), rather than reused for the growing of more tolerant crops. This latter solution, which appears a good alternative, appears to be not possible because of the water rights situation applicable in south western Arizona.

4. EFFLUENT DISPOSAL

4.1 Colorado Basin.

It is expected that by the year 2010 as much as 2.5 million Mg of salt needs to be removed from the Colorado River upstream of Imperial Dam to achieve the 879 mg/L criterion set. A whole range of options and schemes has been or is being evaluated to achieve this objective. Damages to irrigators, municipal and industrial water users is estimated at US$513,000 for every mg/L the criterion is exceeded, or US$54 for every Mg of salt. Figure 2 shows expected trends of salinity in the Colorado River at Imperial Dam.

Approaches to remove salts from the river may be described as follows:

4.1.1. Prevention.

Improved irrigation techniques and concrete lining of channel may reduce accessions to the watertable and therefore reduce groundwater seepage to the river or drainage system. This particularly applies to the Grand Valley Irrigation District (Section 4.1), the Wellton-Mohawk District and the Imperial Valley. The Soil Conservation Service and the Bureau of Reclamation actively pursue this objective in these Districts and several other, smaller districts (Conference papers 17, 26, 27, 28 and 36, see section 5).

4.1.2 Plugging of point source, such as in the Meeker Dome area (Conference paper 31).

4.1.3 Interception of point source salinity and:

(a) Disposal of to evaporation area (as proposed in paper 34).
(b) Deep well injection (paper 30)
(c) Aquatrain project (paper 46)
(d) Use for irrigation, as with effluent from power plants (paper 45).

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Deep well injection has not been practised in this regard but a lot of experience exists with deep well injection of oil brines (paper 32). In Paradox Valley tubewell drainage is to intercept groundwater brine from aquifers at shallow depth to inject it at depths of 300 metres and beyond.

The brine has a salinity of 260,000 mg/L, increasing the river salt load by 186,000 Mg per year. To pump 56 L/s of this brine into the deep aquifer pressures of 7000 kPa have to be applied during injection. Some sort of filtration process, e.g. with diatomaceous earth, is believed to be necessary, prior to injection.

The alternative to this $25 million solution is pumping onto a 700 metres high cliff (mesa) the only location where a site suitable for evaporation ponds can be found.

The Aquatrain project involves transport of coal from the upper Colorado states to California by pipeline, using liquid carbon dioxide as a transport medium. The transport of saline effluent from various point sources during some months of the year really is a side benefit to coal transport to power stations or for export. The saline effluent, derived from hot springs, drainage and seepage locations, would be used for cooling purposes in the power plants, taking away the necessity to interfere with existing water rights and avoiding the problem of increased salinity of the return flow.

Use of the return flows of cooling water from power stations for irrigation is reasonably successful, but in the U.S.A. the element Boron tends to concentrate and accumulate in the soil, affecting crop yields in the long term.

4.1.4 Desalting plant at Yuma.

A reverse osmosis unit, worth $225 million (1979 costs), is being built at Yuma, Arizona, to treat 124,000 ML of Wellton-Mohawk drainage flow with a salinity of 3200 mg/L. After treatment, costing $15 million/year, 34000 ML with salinity 9600 mg/L will be rejected to the Santa Clara Slough in Mexico (Figure 10) and reclaimed will be 90,000 ML, at a salinity of 250 mg/L. The reclaimed water, mixed with drainage flow, then produces about 120,000 ML of water at a salt concentration acceptable to Mexico. This means the cost of reclamation is well in excess of $250/ML (including a capital cost component).

4.1.5 Reuse in Agriculture.

This is not being practised widely, but there are indications that this could be quite successful (papers 43 and 44). In the Imperial Valley a salt tolerant crop such as cotton did not produce less after two years of irrigation with typical drainage flows with a salinity of 4000 mg/L. Germination irrigations however may have to be carried out using a better water quality.

Obviously such a high salinity can only be tolerated if leaching is adequate and salts do not build up. In Australia this is not usually feasible in the Riverine Plain. In addition, the sodium chloride levels in Australia are much higher, calcium sulphates being less. There is no reason to deviate at present from the 400 mg/L standard adopted as a guideline for the downstream end of the M.I.A. channel system.

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On the other hand, work at Tatura (Vic) suggests higher than 400 mg/L salinity may be feasible with pasture irrigation. With cultivated cropping a lower tolerance is applicable.

The new salinity handbook, being finalised at the U.S. Salinity Laboratory at Riverside (California) gives relations of magnesium/calcium ratios as affected by salt concentration and calcium/sodium ratios. The conclusion of work in recent years is that there is no single criterion for water quality as far as sodium adsorption ratios (S.A.R.) are concerned but that relations with other important ions need to be considered as well.

4.2 Red and Brazos River Areas.

Salt pollution into the rivers occurs in upstream reaches. The U.S.Army Corps of Engineers has investigated and identified a number of sites where such seepage flows are concentrated. The brine is near saturation in some instances (200,000 mg/L) and comes from underlying Permean sediments from which it is conveyed to the incised stream beds through Dolomite and other formations. The Permean Sediments occur from Montana through Kansas and Oklahoma into north western Texas.

Control measures include (Conference papers 13, 14, 15, 33):

4.2.1 Plugging (or ring tank) of point source.

Usually not successful as brine may well up at another location nearby. At one location a circular ring tank was constructed around the point source and a head of water put on it to prevent further pollution of the stream. The hydrostatic head in the Permean sediments is usually only about 1 - 2 metres above the river bed.

4.2.2 Well Pumping and diversion.

Investigations were carried out at Jonah Creek, a tributary of the Prairy Dog Town Fork of the Red River (Figure 11). The complex geology caused an insufficiently large area to be affected by any one tubewell.

4.2.3 Low flow diversion and disposal to brine lake.

One such area is at Truscott where a $25 million dam has been constructed. A 35 km pipeline to divert low flows at Bateman from the South Fork Wichita Creek (Figure 11) by an automated pumping station has been finalised also, but operation awaits completion of an inflatable weir structure in the creek. The 900 mm (average) diameter pipeline is made of fibreglass.

4.2.4 Deep Well injection.

One point source was temporarily diverted through a pipeline to a deep well. Experience using this method with corrosive brine solutions exist in the oil industry (paper 32). It is recognised that any surface water will have to be desilted and filtered before deep well injection.

...

4.2.5 Damming of creek and diversion of fesh flows.

The dammed off portion then becomes an evaporation site, with levels corresponding to the underlying aquifer pressure.

Control measures for the Red River are being implemented as they have a suitable Benefit/Cost ratio, but projects for the Brazos and Arkansaw Rivers proved generally uneconomic or marginal only.

4.3 San Joaquin Valley.

Drainage disposal in the San Joaquin Valley (Section 2.4) is either to the rivers, to the partly constructed Valley Drain which runs into a 500 hectare swamp, or to group evaporation areas or to private evaporation ponds. Reuse as an option is limited as it is generally accepted that drainage water with a salinity of 10 dS/m should not be reused, or diluted to be reused.

Evaporation areas are the main alternative, which can be resorted to whilst the Valley Drain does not go ahead. Several points emerged whilst visiting this area.

(a) Construction is similar to the Wakool - Tullakool evaporation ponds. Internal slopes in the Tulare Lake Drainage District are 8 to 1, external slopes steeper.

(b) In the Tulare District one hectare of evaporation area is anticipated for every nine hectares tile drained.

(c) Problems with seepage are small where the Corcoran Clay underlies the landscape.

(d) Farm evaporation ponds are usually shallow and fairly cheap in construction.

(e) When a problem emerges, such as in the south Fork of the Kings River area, a group of farmers may get together to decide on siting, distribution of costs and location of pipeline.

(f) Surface drainage flows should be kept separate from tile drainage flows. Where tile drainage flows are not very salty reuse should be considered to reduce the required size of the evaporation area.

(g) One instance of increased permeability of the soil due to electrolyte concentration and SAR (Sodium absorption ratio) was brought to my notice. The permeability of the soil increased from 0.5 to 6 mm/day preventing salts to accumulate at the soil surface. In such a situation interception and pumping back of seepage may not be acceptable. Soil evaluation and study of the impact on the groundwater environment are most important.

In this report a decision on any evaporation area in areas with deep watertable levels can only be taken after due consideration. For instance, if effluent of 1000 - 2000mg/L was diverted from the Barren Box Swamp near Griffith to a site near Gunbar, then a percolation rate of

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only 0.3 mm/day would result in all salts being added to the deep groundwater, and none would precipitate at the soil surface.

(h) Accumulation of minor elements in the brine. There have been instances of deformations in birds and other wildlife reported. It is unclear whether concentration of Selenium in evaporation ponds is responsible for this phenomenon or whether another mechanism is involved, e.g. Botulism a disease related to breakdown of organic material such as straw (in nearby swamps).

4.4 Other Areas Visited.

4.4.1 Wellton Mohawk Scheme (Section 2.2).

Water is disposed of through a channel bypassing Yuma and running for another 50 kilometres to the Santa Clara Slough, near the gulf of California in Mexico (figure 10).

To reclaim most of this water a $225 million desalting plant is being built at Yuma, Arizona (sections 4.1.4 and 5.2).

Reuse for irrigation appears to be a viable proposition as tubewell effluent often is fairly low (1000 - 2000 mg/L, average 3200 mg/L).

4.4.2 Imperial Valley (Section 2.3).

Any tile drainage is mixed with farm runoff and some channel spill and flows into the Salton Sea. The level of the Salton Sea has been rising in recent times, causing concern. Improved irrigation practices are being implemented. Reuse of effluent appears to be a viable option in this District and is being demonstrated in experiments (Conference paper 43).

5. THE INTERNATIONAL SYMPOSIUM "STATE OF THE ART CONTROL OF SALINITY.

5.1 General Observations on Salinity Control.

The Conference, attended by 160 delegates and speakers of a variety of public and private institutions in the U.S.A. and Australia, focussed on salinity control problems in a variety of situations. The appendix below gives titles of papers and names of speakers.

Whilst the water quality aspects of river systems, such as the Colorado and Murray Rivers, dominated the conference, other aspects, such as dry land salinity (papers 38 and 53), identification of salinity sources (papers 21, 48 and 54) and leaching together with agricultural reuse of saline drainage effluent (papers 43 and 44) were also given attention.

Salt pollution of the Colorado River, comparable in length and flow with the Murray River, but different in many other respects, got most attention, with more than half of all papers devoted to the theme. This included organisational aspects (e.g. papers 1, 2, 6, 7 and 29), monitoring and modelling aspects (e.g. papers 10, 11, 16, 17 and 20), case studies of irrigation areas and their impact on river salinity (e.g. papers 17, 26, 27, 28, 36 and 39), case studies of non agricultural salt pollution (e.g. papers 10, 16, 21, 30, 31, 34 and 40) and certain specific solutions, such as the Yuma desalting plant (paper 41).

The Conference proceedings will not be generally available until early 1984, however information from this symposium relevant to the study tour has been included in this report.

5.2 Major Projects.

Apart from the agricultural approaches to reduce groundwater return flow and non-agricultural approaches, such as salt interception and diversion of effluent, other solutions were presented also, e.g., the CREST programme, aiming to increase river flows by a cloud seeding programme to increase runoff (Paper 1). However, although the proposal suggests a benefit/cost ratio of 9 - 12 to 1 for this US$88 million programme (over 8 years), there are also sceptics who claim that there is no solid evidence that cloud seeding will work.

Another major proposal is the Aquatrain proposal (paper 46), to convey coal from Utah and Colorado in a liquid carbon dioxide slurry through a 2000 km pipeline to the coastal areas of California. This pipeline would occasionally be used to convey salt effluent from non agricultural point pollution sources, such as Glenwood Springs (paper 34) and Paradox Valley (paper 30) to the sea, or to power stations where it may be used for cooling purposes. This US$2-3 billion project has moved from the conceptual stage to the plan formulation stage as the economics for coal companies has improved because of continually increasing railway freight rates for coal.

Another huge capital expenditure project, the Yuma Desalting complex, is about one quarter complete at present. Critics of this project are abundant, because:

(a) It will cost about $US250/ML to reclaim the water.

(b) It is cheaper to for instance buy land off farmers in Wellton-Mohawk to reduce seepage and drainage return flows.

(c) Flows in the Colorado are above average in recent years, 1983 being a flood year. There is plenty of dilution at present.

(d) Water rights in upper Colorado states have not been taken up yet, and could be bought out.

This project however, is going ahead because of the complexities of legal issues related to water rights and the moral obligation to Mexico. In a way the inability to save water by legal means has forced the decision (in 1973). Fortunately the amount of drainage from the Wellton-Mohawk Scheme has declined substantially, becuase of improvements in irrigation efficiency. As a result, the desalting plant has been downgraded in size to about 124,000 ML/year.

5.3 Planning and Economics.

It was outside the objectives of this trip to study U.S.A. water policies and institutional structures as described in e.g., papers 6 and 7. However, it is clear that the U.S.A. situation is much more complex than in Australia, where State Water Authorities have most of the control. In the U.S.A. the water districts are private organisations, more states are involved, water rights are defined differently in different districts etc. Every time a decision needs to be made the processes of negotiation, consultation etc. are much more lengthy and more likely to fail.

Despite this a lot of progress has been made. As far as the Colorado upstream irrigation districts are concerned, including Wellton-Mohawk, the Bureau of Reclamation, the Department of Agriculture and the Environment Protection Agency act together, each being assigned specific role by the Colorado River Basin Salinity Control Act, Public Law 93-320. The Bureau of Reclamation has the leadership function. The Department of Agriculture, through the Soil Conservation Service, is responsible for the planning and construction of on-farm works to reduce salt in the groundwater return flows to the river.

For each District the planning process for on-farm works includes (Paper 7):

1. Defining the problem.
2. Inventory and analysis.
3. Formulation of alternative plans.
4. Prepare display of effects.
5. Comparison of alternative plans.
6. Selection of recommended plans.

The processes, which include co-operation of farmer groups from the outset, are quite impressive and include substantial economic analysis. The final plans are usually selected on a number of criteria, such as maximised salinity reduction, total on-farm and downstream monetary benefits and water conservation.

After construction of on-farm works the Soil Conservation Service retains a supervisory role and often assists in irrigation scheduling services. In the Wellton-Mohawk Scheme this role is taken up by the Irrigation Management Services of the Bureau of Reclamation.

Economic evaluation of projects therefore are part of normal procedures. It is interesting to note that in the south west of the mid west, where the US Army Corps of Engineers is evaluating projects the criterion to proceed are based on Benefit/cost analysis, (papers 3, 13, 14, 33 and 47), but the Bureau of Reclamation, for Colorado salinity control projects, uses the term cost-effectiveness (paper 1). This is due to the objectives of the projects. The Brazos River, Red River and Arkansas River projects are conventional in economic terms, but with the Colorado System the objective is to keep water quality at Imperial Dam below 879 mg/L (e.g., paper 2). Projects are therefore evaluated on basis of the cost to achieve that objective, even though the cost of the project may exceed the 1982 figure of US$513,000 for every mg/L that the criterion is exceeded.

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The objectives, aiming to reduce salt influx upstream to protect water users downstream, allows a Federal Funding of up to 75% of on-farm projects to reduce accessions to the watertable and groundwater seepage to the river. The remaining 25% relates to the benefit the farmers themselves are getting. The most downstream Irrigation District, Imperial Irrigation District, is not getting this subsidy.

5.4 Miscellaneous.

Through the Conference and the post conference tour awareness was also increased with regard to brine pollution from oil well exploitation, not only in Utah (paper 32) but also in Texas. These brines were polluting water courses until legislation prevents this. However, shallow aquifers are still being polluted in many places where deep well injection is not practised, or is not feasible, because disposal into evaporation ponds often leads to deep percolation in a generally rather permeable environment.

Dry salting of agricultural lands in the mid west is also spreading. It appears that little regard is at present being given, in some states e.g., Texas, about the ultimate effect of this process on the land, or pollution of streams, once sub-surface drainage is installed.

The Conference perhaps lacked in that there were no papers on subsurface drainage criteria or disposal of salts in agricultural regions. Such information was collected as much as possible during the post conference tour to various Irrigation Districts and various institutions, as described elsewhere in this report.

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6. CHRONOLOGICAL ACCOUNT.

Itinerary

July 11	Travel Griffith to San Francisco via Sydney.
July 12	Travel to Salt Lake City with United Airlines.
July 13,14,15	Attendance International Symposium "State of the Art Control of Salinity". Presentation of paper entitled "Salinity control problems associated with Irrigation in south-west New South Wales", Australia. Authorship A. van der Lelij and S.E. Flint (Principal Research Officer).
July 16	Travel by car, courtesy Bureau of Reclamation, Denver with Mr. David Merritt of the Bureau, Mr. Keith Collett, S.R.W.S.C. Victoria and Dr. Robert A. Wildes, Senior Research Officer, Dept. of Agriculture, Tatura, Victoria. Inspection Huntington Power Plant,disposal of blow down cooling water using irrigation techniques (paper 45) near Price, Utah. Overnight stay at Moab, Utah, along the Colorado River.
July 17	Travel by car courtesy, Bureau of Reclamation, Denver to Grand Junction Colorado. Visit to Paradox Valley, where the Dolores river, a tributory to the Colorado, picks up brine groundwater seepage coming from underground salt domes. Investigations by groundwater pumping, disposal to evaporation area (temporary) deep well injection to 300 metres (future - conf. paper 30). Stream salinity and flow gauging using remote sensing via satellites.
July 18	Grand Junction Irrigation District. Over-irrigation causes saline groundwater return flows to Colorado River (paper 17). Tour guided by Mr. R. Medler, supervising Hydraulics Engineer, Bureau of Reclamation, Mr. Jim Courier and Mr. Dan Crabtree, both of the USDA Soil Conservation Service. Inspection of works to reduce channel seepage and on-farm deep percolation. This includes concrete lining of channels, trash screening structures, level ported ditches to irrigate,border checks, cablegation, automated gated pipes and Sideroll sprinkler irrigation (paper 27). The effect of Stage I of this project shows a small beneficial effect which is being monitored (paper 28).
July 19	Travel by rented car to Denver, Colorado. Inspection of Glenwood - Dotsero Springs, one of the major identified salt sources into the river (paper 34).
July 20	Travel by United Airlines to Fort Worth, Texas. Party joined by Mr. Keith Lewis, Director-General of E. & W.S.D. of South Australia and Dr. Baden Williams of CSIRO, Land Use Research, Canberra.

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July 21 Visit of Soil Conservation Service, Fort Worth Division, which supervises 12 South Eastern States. Discussion with Dr. Richard Wennberg, Supervising Drainage Engineer. A drainage model has been developed in eastern USA suitable for relatively humid areas. This is being modified for irrigated areas to identify design criteria (see August 2,c). Other points:- (a) increased dry land salinity, in area from North Texas to Montana, tending to increasing demand for subsoil drainage (papers 38, 53) and increased discharge of saline effluent into rivers.

:- (b) brine discharge from oil wells, polluting soil and groundwater resource.

pm U.S. Army Corps of Engineers, Fort Worth District. Colonel R. Stroup, Mr. J.A. McGrory, Mr. W. Banks (Engineers). Slide show of Red, Brazos and Arkansas River Systems pollution by seepage of brine into upstream reaches from Permean sediments. Control measures include diversion by pipeline of brine to evaporation ponds, deep well injection, damming up of springs and bypassing of fresh flows past identified salt intrusions, (papers 3, 13, 14, 15, 33 and 47). Only the Red River proposals appear economic but are only partially implemented.

July 22 Inspection of parts of Brazos River and Red River systems using Army helicoper supplied by US Army Corps of Engineers. Travel to Dove Creek Salt flat (Brazos River) where saline seepage is (very) evident. Travel to Truscott Dam, constructed to contain future brine diversions by pipeline from several tributories of Red River. Inspection of 34 km pipeline from Bateman, on the South Fork of the Wichita River, and pumping station. All low flows of this creek are to be pumped to Truscott Dam. Return Fort Worth via Breckenridge, Texas. Dr. Baden Williams, leaves party.

July 23 Travel to Phoenix, Arizona via Denver with United Airlines.

July 24 At Phoenix.

July 25 Visit to USDA, Agricultural Research Service, Water Conservation Laboratory. Dr. Herman Bouwer, Director, Dr. Al Dedrick, Dr. John Replogle, Dr. Paul Pinter. Design of level basin irrigation systems to reduce accessions to watertable, e.g. in Wellton- Mohawk Irrigation District. Irrigation scheduling using infrared spectrometers to measure plant stress. Designs of irrigation flow measurement structures, in particular long throated weirs. Improved techniques may reduce quantities of percolation and therefore subsoil drainage, which has an effect on the sizing of the Yuma desalting plant. Travel to Yuma, Arizona by Sunaire.

July 26 Visit Office Bureau of Reclamation, Yuma. Mr. Ken Trompeter, Project Manager, Mr. Ken Sidebottom, Ass. Project Manager, discussion re Yuma Desalting Plant and Bureau's involvement with Wellton-Mohawk Scheme through Irrigation Measurement Services. Tour of Yuma Desalting Plant (paper 41) by Mr. Paul McAleese, Design Engineer. After lunch, inspection of Wellton-Mohawk Irrigation District, courtesy Mr. Stan Conway, Soil Scientist with the Bureau of Reclamation. Visit to District Office, Manager, Mr. Clyde Gould. The District is under pressure to improve efficiency because subsoil drainage flows returned, irrespective of the increased salinity. Mr. Thomas Shinn, Soil Conservation Service accompanied the party to on-farm improvement works. Tubewell drainage in this District was inspected and method of operation discussed. Groundwater contour maps help to decide on operation. Pumps aim to keep watertables below 2.4 metres, irrespective of quantity of percolation. There are no specific design criteria.

July 27 Travel by rental car to Imperial, Imperial Irrigation District. Mr. Robert Wilson, Manager, Mr. George Wheeler, Assistant Manager and Mr. Myron L. Corfman, Supervisor Drainage Unit. Discussion of channel and farm efficiencies. The District is being sued for allowing increased level of Salton Sea, into which all drainage goes, which is about 33% of supply of 3.2×10^6 ML max. water right. This drainage comprises of less than 5% channel spills, 5 - 15% surface runoff and about 20% (average) subsoil effluent. Fines apply for those allowing more than 15% runoff and this is strictly policed.

Record keeping of installation of subsoil drainage is impressive but procedures for design appear not more advanced than those for horticultural areas in the MIA.

Field inspection of automated channel control structures, construction of new concrete channels, tile drainage pumping and runoff measuring boxes. Travel to San Bernadino, California. Mr. K. Lewis leaves party.

July 28 Travel by rented car to Fresno, California.

July 29 At Fresno, visit of California Department of Water Resouces. Mr. Victor McIntyre, Chief, Drainage Division and Mr. Arvey Swanson, Engineering Geologist. Travel to Tulare Lake Drainage District, courtesy of the above agency. Discussion with Mr. Stephen Hall, Manager. Parts of the District, and the Westland Irrigation District to the north are threatened by high watertables and salt. Tile drainage is being installed. In this district diversion is to evaporation basins, now totalling 1340 hectares in area, of which half are used at present. A pipeline traverses the district (90,000 ha) and individual farmers may hook in. Whole scheme funded by landholders, including Boswell (40,000 ha). One hectare of evaporation area is anticipated for every nine hectares of drained land.

Soils of evaporation area appear quite suitable for this purpose (high watertable, low permeability underneath). Further north farmers may have to sacrifice some land for evaporation areas, as continuation of construction of the Valley Drain is halted because of environmental and financial considerations. One such farm evaporation pond was inspected in the South Fork of the Kings River Area. Farmers seem to be left to their own devices when it comes to design of subsoil drainage. Soil Conservation Service offers some help.

July 30, 31 Mr. Keith Collett leaves party. Dr. R. Wildes and Mr. A. van der Lelij return to Riverside, California, by rented car.

August 1	Riverside, California, USDA, Agricultural Research Service, Salinity Laboratory.

Discussions:

(a) Dr. A. Jan van Schilfaarde (Director) General drainage philosphy and design criteria. Exact criteria are unlikely to be achievable.

(b) Dr. Glen Hoffman. Results of various experiments in Imperial Valley etc. Minimum leaching concept (paper 43).

(c) Dr. Sabina Goldberg. Likely change of permeability of soils underneath evaporation ponds.

(d) Dr. Frank Dalton. Time Domaine Reflectometry. Development of instrumentation to measure moisture level and salinity level simultaneously.

(e) Inspection of leaching trials, and various lysimeter studies.

August 2 — University of California, Riverside. Discussions:

(a) Dr. J.D. Oster. Cation effects on permeability and soil structure. Effect of magnesium.

(b) Dr. J. Letey - Variability of infiltration and its effect on yields of crops, as affected by different soil salt levels and irrigation efficiencies.

(c) Dr. A. Chang. Adjustment of drainage model to suit irrigated agriculture conditions. Development of drainage criteria.

(d) Prof. F. T. Bingham. Boron effects in soils and plants.

(e) Prof. L.H. Stolzy. Miscellaneous topics.

August 3 — Travel to Davis, California, by Air Cal. Dr. R. Wildes goes his own way.

August 4, 5 — University of California, Davis

(a) Prof. K.K. Tangi, Land, Air and Water Hydrosalinity modelling.

(b) Prof. J.W. Biggar. Variability hydraulic conductivity versus drainage design criteria.

(c) Dr. D. Nielsen - How to take advantage of variability of soil parameters, time series analysis, kriging analysis.

(d) Dr. D. Rolston - As for Dr. Nielsen.

Depart Davis by Greyhound bus to San Francisco - travel to Sydney with Quantas Airways.

August 7 — Arrive Sydney 6.30 am. Travel to Griffith with Air NSW, Arrive 8 pm.

7. MAIN CONCLUSIONS:

The major conclusions relevant to the purpose of this study trip are:

(a) The prevailing opinion of scientists in the U.S.A. is that drainage effluent should be reused if it is not too salty for a more tolerant crop during a less sensitive stage of its growth. If the salinity is too high the effluent should be disposed of by means other than dilution and reuse. The level of salinity still suitable for reuse is about 5000 mg/L for U.S.A. conditions.

(b) Evaluation of drainage criteria in irrigated areas is difficult, complicated by rapid changes in soil moisture depletion above the water table. Often the deep percolation factor, or the up and downward groundwater movement below the depth of the tiles dominates. Quantifying these factors requires detailed knowledge of a complex groundwater hydrology, which is not always feasible.

The drainage requirement is affected by these factors and the leaching requirement, which may be determined as a function of the salinity of the irrigation water.

(c) Effluent disposal by means of evaporation is practised widely, particularly in the San Joaquin Valley. It may consist of group schemes, where farmers have got together to implement a scheme, or individual ponds, located on the farmers property. Investigations preceding construction of these ponds is an important pre-requisite.

These conclusions may be incorporated in planning of further investigations of salinity control in irrigated areas of southern New South Wales.

D. West, Government Printer, New South Wales 1983

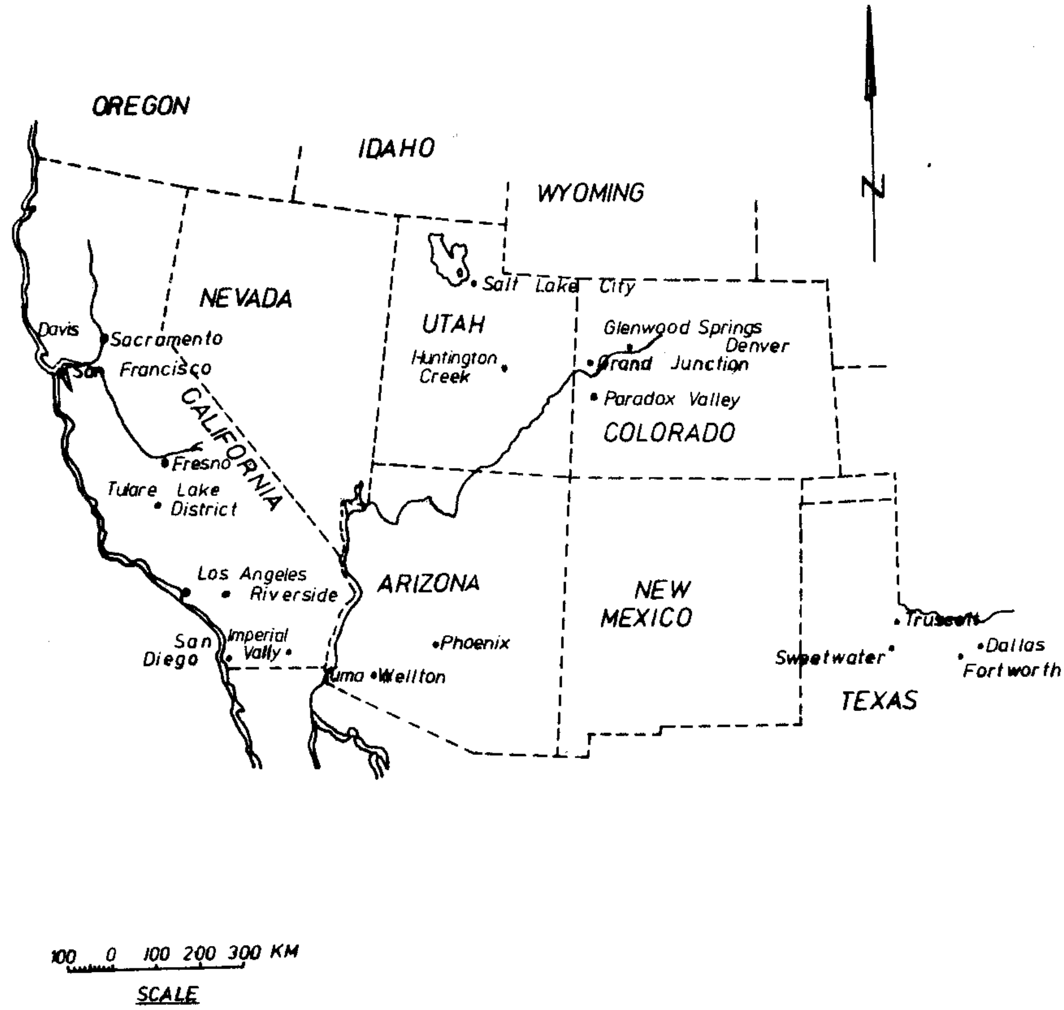


FIG I. CENTRES VISITED
WESTERN UNITED STATES

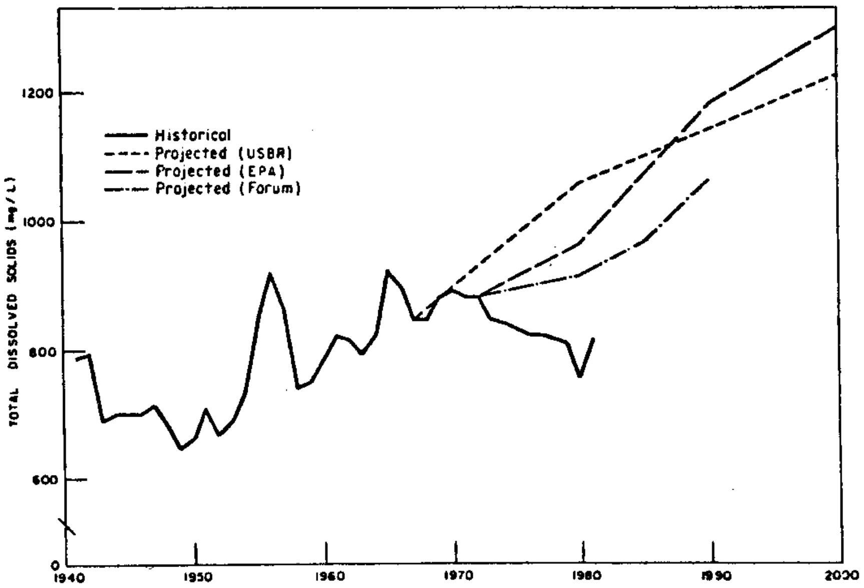


Figure 2. Historical [1] vs. projected [4, 5, 6] TDS at

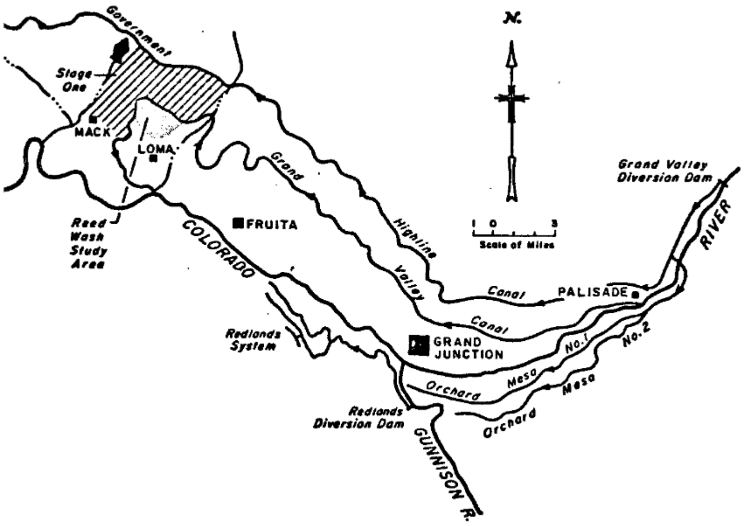


FIG 3. GRAND JUNCTION IRRIGATION DISTRICT

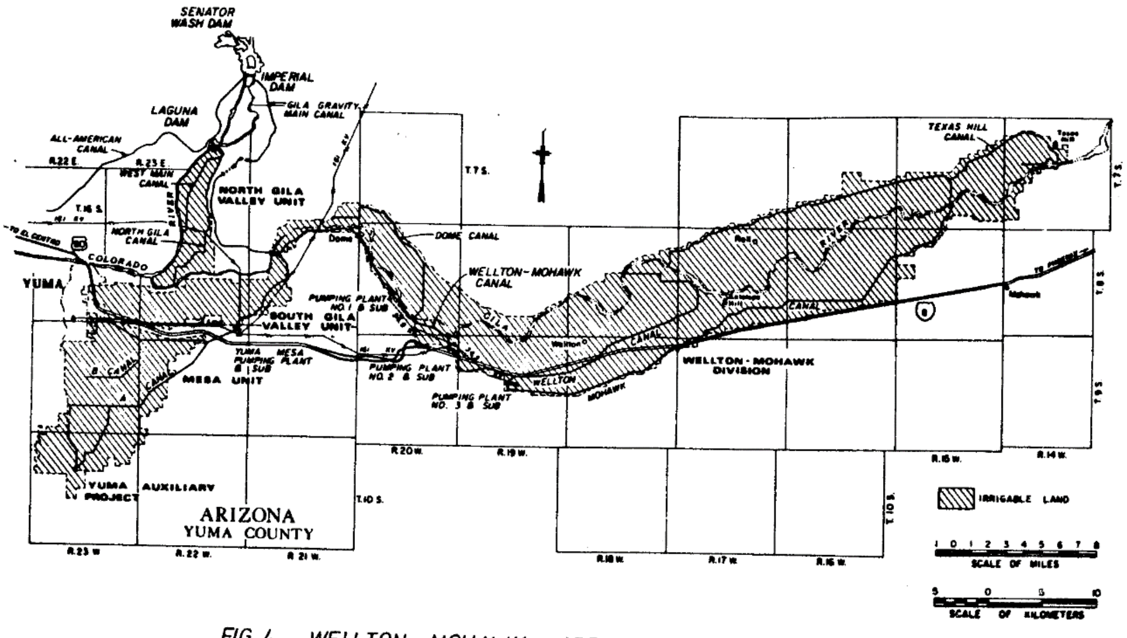


FIG 4. WELLTON - MOHAWK IRRIGATION DISTRICT

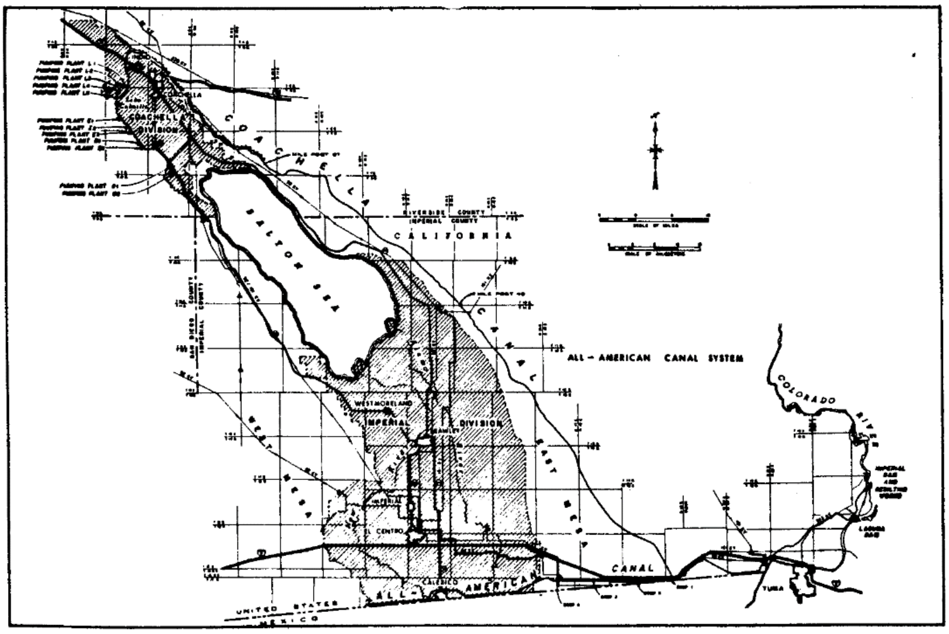
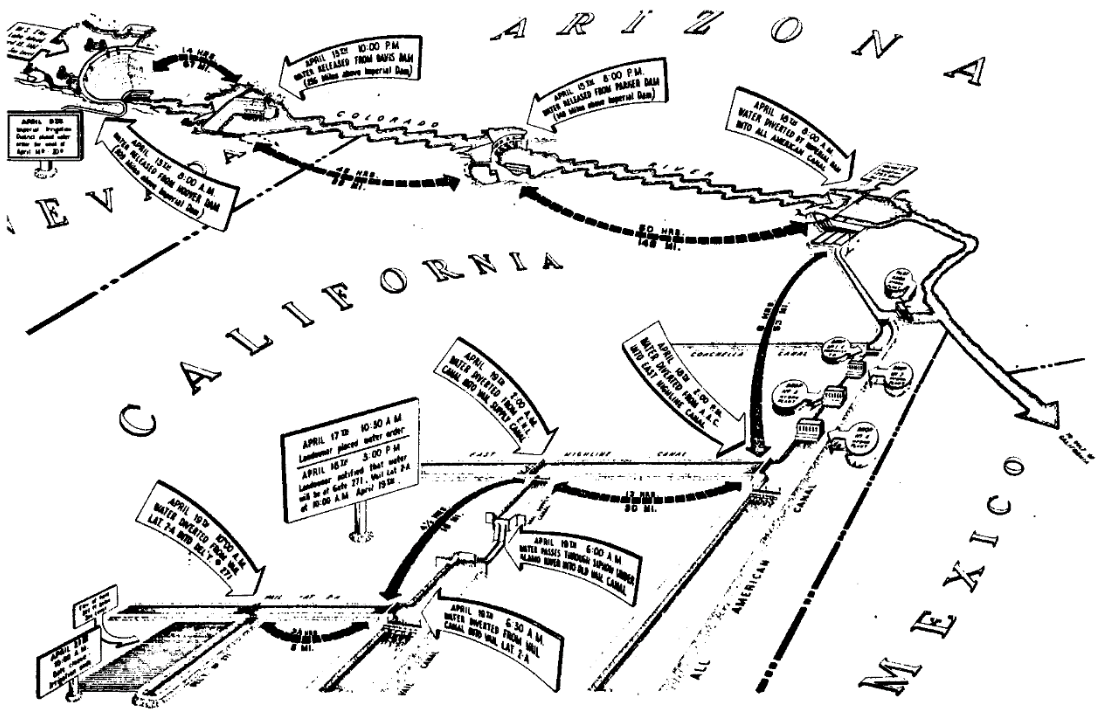


FIG 5
IMPERIAL IRRIGATION DISTRICT

FIG. 6

IMPERIAL IRRIGATION DISTRICT
WATER TRANSPORTATION
HOOVER DAM TO USER



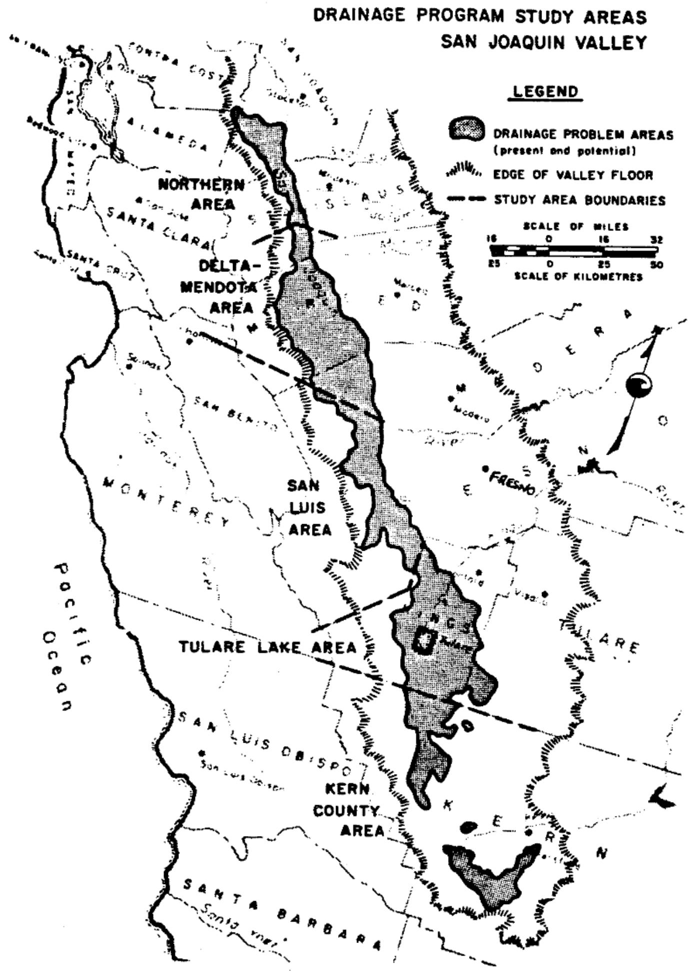


FIG. 8. DRAINAGE PROBLEM AREAS IN THE SAN JOAQUIN VALLEY.
(FROM: Interagency Drainage Program Report 1980)

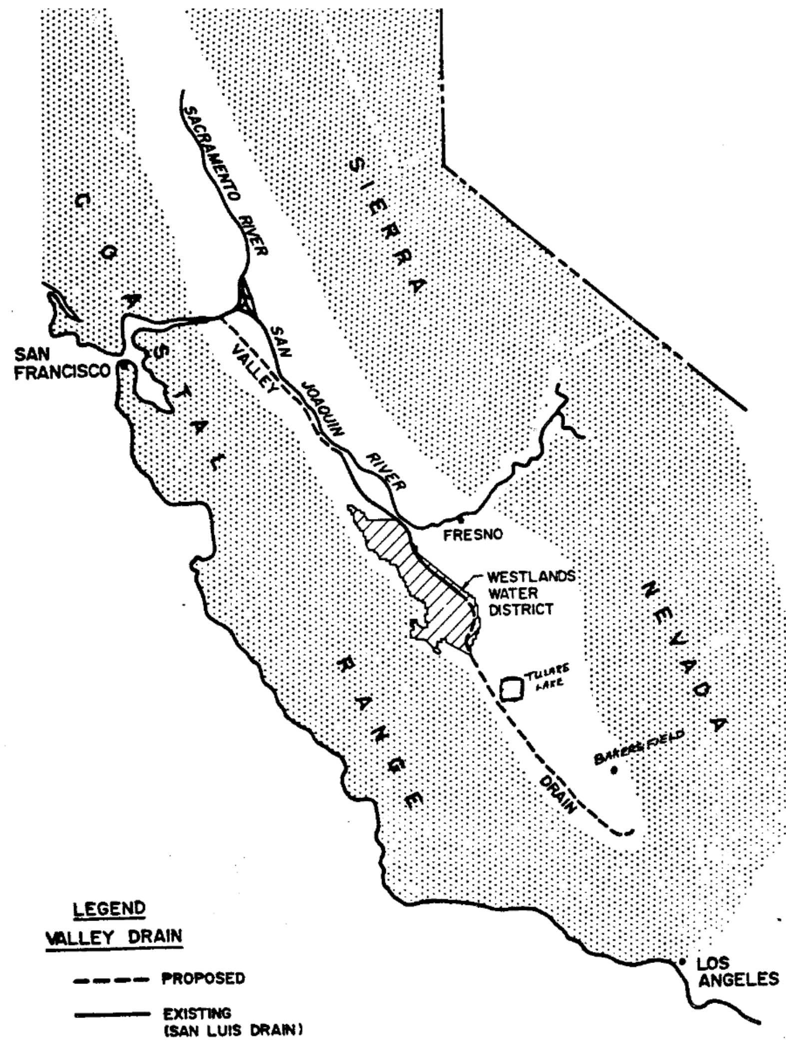
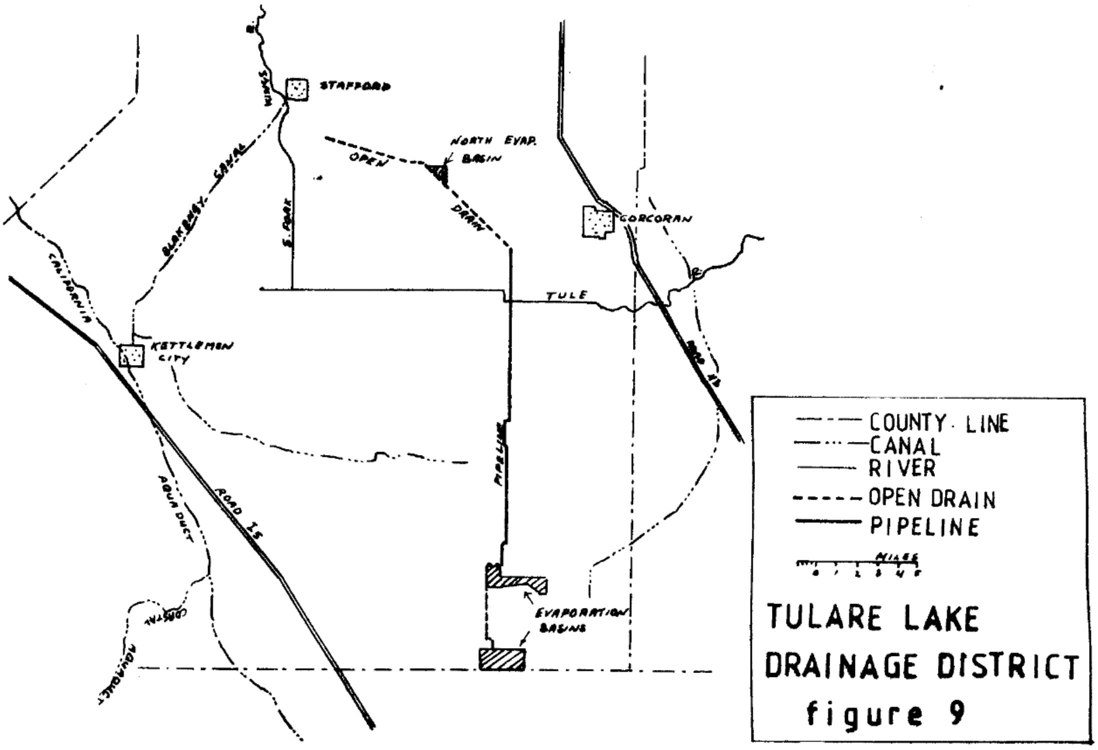
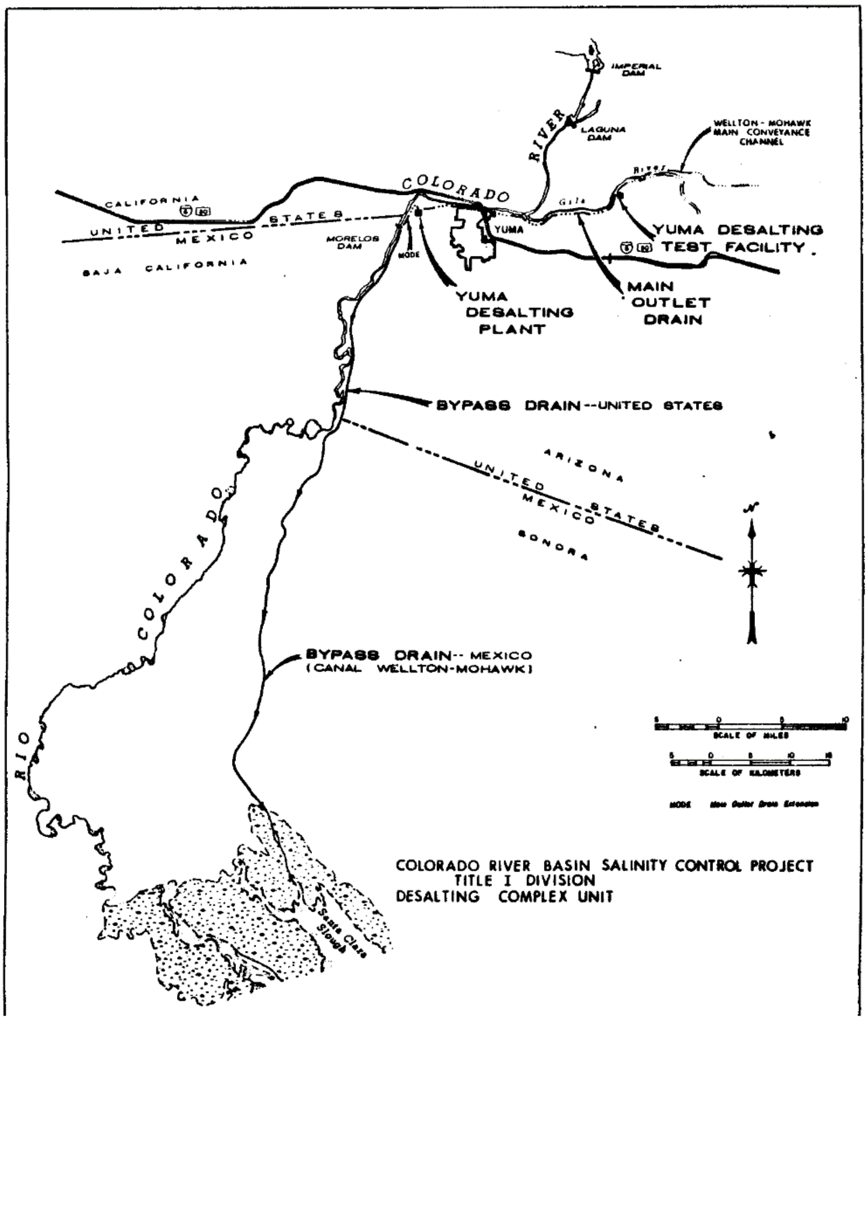


FIG 7 SAN JOAQUIN VALLEY CALIFORNIA



TULARE LAKE DRAINAGE DISTRICT
figure 9



COLORADO RIVER BASIN SALINITY CONTROL PROJECT
TITLE I DIVISION
DESALTING COMPLEX UNIT

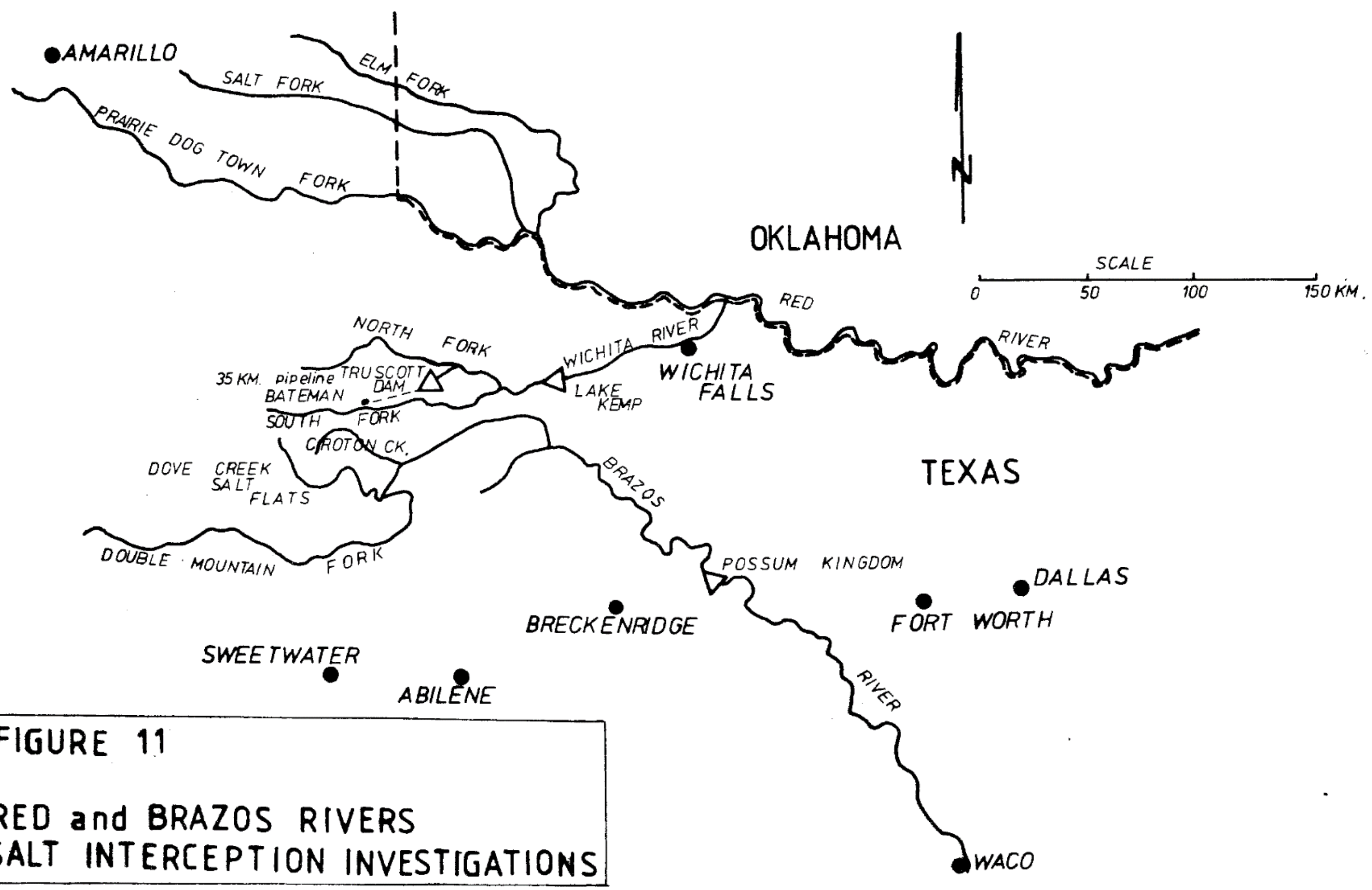


FIGURE 11

RED and BRAZOS RIVERS
SALT INTERCEPTION INVESTIGATIONS